2011 Stock Assessment and Fishery Evaluation Report for the Tanner Crab Fisheries of the Bering Sea and Aleutian Islands Regions

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Preamble

At the time of developing this draft 2011 SAFE report, only survey biomass data through 2010 and fishery data through the 2009/10 season are available. Until the 2011 survey and 2010/11 fishery data are incorporated in the assessment, much of the ensuing discussion on the status of the stock and OFL calculation is taken from the 2010 Tanner crab SAFE (Rugolo and Turnock 2010). This discussion will be updated and finalized with the 2011 SAFE report to the CPT in September 2011.

A length-based Tanner crab stock assessment model (TCSAM) is under development. A report on the current performance of the TCSAM is provided in Appendix A. The Tanner crab management plan stock data table is presented in Appendix B.

Status of the 2010/11 Stock

As reported in Rugolo and Turnock (2010), Tanner crab MMB in 2009/10 declined substantially from previous years and fell below the minimum stock size threshold at survey time (MSST=0.5B_{REF}). MMB at the time of the 2010 survey declined 8.3% relative to 2009. Under the current plan, MMB estimated at the time of mating (mid-February) is gauged against the MSST to determine its status relative to the overfished criterion. This accounts for losses due to natural morality from the survey to the time of mating and losses due to directed and non-directed fishing. For the status determination, B_{REF}=83.80 thousand metric tonnes (t) and the overfished status criterion, MSST, is 41.90 thousand t. After considering stock losses from natural mortality and the 2009/10 fisheries, the 2010 MMB at the time of mating was 28.44 thousand t. This represents a ratio of 0.34 relative to B_{REF} which is below the limit that defines an overfished stock. The 2009/10 Tanner crab stock was determined to be overfished by NOAA Fisheries based on the 2010 stock assessment (Rugolo and Turnock 2010).

For the 2010/11 fishery, the State of Alaska closed directed commercial fishing for Tanner crab east and west of 166^{o} West longitude (Pengilly 2010). The SOA's harvest strategy level of opening the Bering Sea District to fishing is 21 million pounds (9.5 thousand t) of mature female biomass in the Eastern Subdistrict at the time of the survey. Mature female biomass relative to this threshold is defined as the estimated biomass of females > 79 mm carapace width. The 2010 survey estimate of mature female Tanner crab biomass was 15.1 million pounds (6.8 thousand t).

For the 2010/11 stock status determination, losses from the time of the 2010 survey to mating in 2011, and losses from directed and non-directed fishing are considered. Even under the zero retained catch strategy implemented in 2010/11, there will be no change in the 2010/11 stock status relative to the overfished determination. MMB at the time of the survey declined 8.3% between 2009 and 2010. Instantaneous natural mortality losses between the 2010 survey and 2011 mating time occurr at the rate 0.15. Between the 2010 survey and the time of mating in 2011, if no natural mortality losses occurred, nor losses from the 2010/11 non-directed pot and groundfish fisheries, $MMB_{2010/11}/B_{REF}$ will be less than 0.34 estimated for the 2009/10 stock Once all non-directed and natural mortality losses are included, $MMB_{2010/11}/B_{REF}$ will be less than 0.34. The Tanner crab stock will remain overfished in 2010/11.

Executive Summary ***(2010 SAFE – To Be Replaced)***

In 2010, Tanner crab MMB at the time of the survey was estimated at 32.08 thousand t representing a 9.1% decrease relative to 2009. Mature male abundance fell 9.4% relative to 2009 and legal males were sparsely and patchily distributed throughout the survey range with regions of highest abundance in southwestern Bristol Bay and the Pribilof Islands. The total abundance index for legal males increased 13.7% to 8.0 million crabs between 2009 and 2010 owing largely to a high-density station in the area of the Pribilof Islands. Legal males were distributed 56.1% (4.5 million crabs) east and 43.9% (3.5 million crabs) west of 166° west longitude which was comparable to the apportionment in 2009 (Rugolo and Turnock 2009). The 2010 abundance index for pre-recruit male crabs (110-137 mm cw) declined 15.4%, and that for small males (<110 mm cw) increased 13.9% relative to 2009. Total male abundance increased 8.5% between 2009 and 2010 which was largely driven by the increase in small males (<110 mm cw). Comparison of the male size frequency distributions between 2006 and 2010 revealed a decline in male abundance above 70 mm cw between 2009 and 2010 (Figure 10 e), and a relatively increasing percentage of old shell crabs in the mature male stock (Figures 10 a-e). The recruit mode (20-40mm cw) seen in 2009 (Figure 10 d) grew to 30-50 mm cw in 2010 (Figure 10 e). The decline in male abundance in 2010 above 70 mm cw coupled with the relatively high percentage of old and very old shell males in the mature stock is an issue of concern regarding future reproductive potential of this stock.

Large female (>=85 mm cw) Tanner crab revealed a substantial 49.7% decrease in abundance in 2010 relative to 2009, and mature female biomass was comprised of 79.5% old shell females. Among all female Tanner crab in 2010, 15.5% were collectively old shell and 82.7% new-hard shell. Small females (<85 mm cw) increased by 13.8% relative to 2009. Total 2010 female abundance increased 8.5% which was largely influenced by the increase in small females <85 mm cw. Total survey abundance of males and females combined increased 9.3% over that in 2009 driven by the increase in both small male and small female crabs. The survey length frequency distributions of female Tanner crab from 2006-2010 revealed consistently declining abundance across the size modes and the general failure of modes of abundance to persist inter-annually (Figures 11 a-e). The prominent length mode between 65-75 mm cw seen in 2006 did not persist in expected levels of abundance in 2007 through 2010. The moderate mode of female abundance above 60 mm cw seen in 2009 (Figure 11 d), which was dominated by old and very old shell females, declined substantially in 2010 (Figure 11 e). A modest mode of new shell recruits seen in 2009 at 25-30 mm cw persists in 2010 at 35-50 mm cw. A relatively strong recruit mode (35-50 mm cw) is apparent in the 2010 survey data (Figure 11 e).

Tanner crab is managed as a Tier-4 stock. The proxy B_{MSY} for OFL-setting is the reference biomass (B_{REF})=83.80 thousand t of MMB at the time of mating estimated as the average survey male mature biomass at mating from 1969-80 inclusive. For Tier-4 stocks, the F_{OFL} is derived using an F_{OFL} Control Rule based on the relationship of current male mature biomass to B_{REF} as a proxy for B_{MSY}. Here, $F_{OFL}=\gamma M$**.** The Amendment 24 and its associated EA defines a default value of gamma=1.0. Gamma is allowed to be less than or greater than unity resulting in overfishing limits more or less biologically conservative than fishing at M. Amendment 24 also cautions that γ should not be set to a value that would provide less biological conservation and more risk-prone overfishing definitions without defensible evidence that the stock could support fishing at levels in excess of M. The resultant overfishing limit (F_{OFL}) for Tier-4 stocks is specified in terms of a Total Catch OFL that includes all stock losses (retained catch, discard and bycatch mortalities) for males and females combined by the directed and all non-directed fisheries.

The value of M for EBS Tanner crab is 0.23. For this analysis, gamma is set to 1.0. The projected 2010/11 estimate of MMB at the time of mating is 26.07 thousand t. Relative to B_{REF}, $MMB_{2010/11}/B_{REF}$=0.31. Under the OFL Control Rule, the 2010/11 F_{OFL}=0.05.

For the 2010/11 Tanner crab fishery, we estimated the Total Catch OFL=1,612.1 t for males and females combined. (Note, here we present the catch components are in tonnes for clarity as the values in 1000 t for some components are small at one significant digit). Total losses to MMB in the 2010/11 Total Catch OFL are 1,445.5 t. Directed and non-directed discard losses to MMB in 2010/11 are estimated to be 46.4 t and 1,312.1 t, respectively. The retained part of the catch OFL of legal-sized crabs is 87.0 t. The retained legal catch would comprise 6.4% of the total MMB losses projected in 2010/11. Thus, a significant component of MMB losses is attributed to non-targeted losses under current fishing practices.

Expected discard losses of female Tanner crab from the 2010/11 groundfish fishery and the directed pot fishery combined was estimated at 166.6 t. Estimated exploitation rates on LMB and MMB associated with these projected catches are 0.03 and 0.05 respectively.

Status and catch specifications (1000 t) for EBS Tanner crab.

Year	MSST	Biomass (MMB)	OFL	TAC [E+W]	Retained Catch	Total Catch
2005/06[1/]		39.28		0.73	0.43	1.61
2006/07[1/]		59.18		1.35	0.96	3.15
2007/08[1/]		68.76		2.55	0.96	3.63
2008/09[1/]	43.04	53.63	7.04	1.95	0.88	2.25
2009/10	41.90	28.44	2.27	0.61	0.60	1.69
2010/11	41.90	26.07[2/]	1.45[3/]	0.0		

Notes:
1/ Biomass and threshold definitions based on survey data derived using fixed 50 ft net width area-swept calculations.
2/ Projected 2010/11 MMB at time of mating after extraction of the estimated total catch OFL.
3/ Total catch OFL for the 2010/11 fishery.

In 2009/10, Tanner crab MMB was below the MSST at the time of the 2009 survey, below MSST at the time of the 2009/10 fishery, and below MSST at the time of mating in mid-February 2010. Overfishing did not occur during the 2009/10 fishing year as total catch losses (1.69 thousand t) did not exceed the total catch OFL (2.27 thousand t). The 2009/10 MMB at the time of mating represented a ratio of 0.34 relative to B_{REF}. The 2009/10 Tanner crab stock is determined to be overfished. In 2010 at the time of the survey, Tanner crab MMB declined further relative to 2009 and, once again, even at that time, was below MSST. Under a zero retained catch harvest strategy in 2010/11, therefore, there is no change in the 2010/11 stock status relative to the overfished determination reached in September 2010.

A. Summary of Major Changes

1. Management of Fishery:

In March 2011, the Alaska Board of Fisheries approved a new minimum size limit strategy for Tanner crab that will be in effect for the 2011/12 fishery. The previously minimum legal size limit was 5.5” (138 mm cw) throughout the Eastern Subdistrict. The new regulations established different minimum size limits east and west of 166° West longitude. That for the fishery to the east will be 4.8” (122 mm cw), and that to the west will be 4.4” (112 mm cw). The industry may self-impose retention of crab above 5.5” (138 mm cw) and 5” (127 mm cw) east and west of 166° West longitude, respectively.

2. *Input Data*:

This assessment examined area-swept biomass estimates from the NMFS bottom trawl survey for 1969-1975. Data for years 1969-1973 are not used in the OFL analysis. Previous survey data for 1969, 1970 and 1972-1975 for males and 1974-1975 for females were extracted form historical International Pacific Fisheries Commission (INPFC) documents.

3. Assessment Methodology:

There are no major changes to assessment methodology in this 2011 SAFE relative to the 2010 SAFE (Rugolo and Turnock 2010) in determining stock status or estimating the F_{OFL} and the catch components comprising the

Total Catch OFL. Two additional approaches are added to this assessment to address management strategy changes and MSA requirements:

1. To address the new size limit strategies in effect for the 2011/12 fishery, we propose a method to derive guideline harvest levels that apportions the retained catch component of the OFL to the areas east and west of 166^{o} W longitude (*see* Section F).
2. To address the requirement of the MSA to establish ACLs based on an ABC control rule that accounts for scientific uncertainty in the OFL, we develop a Tier-4 approach to derive an ACL=ABC for the 2011/12 fishery (*see* Section G).

4. Assessment Results:

The 2011 assessment will be completed in September 2011 once 2010 survey and 2010/11 fishery data are available. There will be consequent changes in assessment results for the estimated biomass and Total Catch OFL.

B. Responses to SSC and CPT Comments

1. SSC Comments:

<u>October 2010 Meeting:</u>

In their review of the 2010 SAFE reports, the SSC made the following general comments on eastern Bering Sea Tanner crab:

- *The authors were responsive to SSC comments from June 2010. Lacking an assessment model, the authors continue to base stock status determination on results from the annual summer trawl survey. This year, the revised survey estimates were corrected based on survey net width for the first time and included the 2010 summer survey. The latest results confirm that estimated Tanner crab abundance has fallen below the MSST, which will require a rebuilding plan to be developed by October 1, 2012. The SSC noted a sharp one-year decline in the estimated abundance of mature females. Here, and in similar instances, the SSC would like the authors to report whether such declines are statistically significant.*
- *A stock assessment model is under development, but not yet ready for review. It's imperative that the model be completed for use as a projection model in the rebuilding analysis. A workshop on crab model development, held in February 2011 will be helpful in this regard. As noted in the June 2010 SSC report, the SSC would like the authors to develop a model capable of handling two different minimum size limits in the eastern and western areas, because the Alaska Board of Fisheries may take such an action at their next meeting on BSAI crabs. Also, the SSC looks forward to a model that considers recent results on gear selectivity.*
- *As indicated in the SSC's June 2010 report, the SSC concurs with the CPT that the years used for status determination should be investigated with respect to potential changes in productivity, and a rationale provided for the selected choice. In addition, the issue of Tanner/snow crab hybrids should be examined. Apparently, the hybrids are allocated to one species or the other based on eye color and mouth shape in the landings, but are identified as hybrids in the surveys and not counted toward the survey estimates for Tanner and snow crab. While in practice this could be a conservative approach, it would be useful to know how the current practice affects species-specific catches relative to the specified harvest strategy and whether some species-specific accounting needs to be better reconciled between stock assessments and catch reporting.*

The Tanner crab stock is currently managed under Tier-4 designation using trawl survey biomass estimates to gauge stock status. The Tanner crab stock was determined to be overfished based on the final 2010 stock assessment (Rugolo and Turnock 2010). For the 2011 assessment, the authors will report whether the decline in mature female biomass is statistically significant.

A stock assessment model for Tanner crab is under development. Results on the performance of the model were presented to the Crab Modeling Workshop in February 2011, and to the SSC in March 2011. The Workshop reported that, "As currently formulated, the model is not sufficient for use in rebuilding analysis." The SSC reported in March 2011 that, while improvements to the model following the Workshop "…resulted in noted improvements in model fits, much work remains to be done and the current model is not yet ready for use in stock assessment or stock rebuilding analysis." We agree.

This assessment will propose an approach for review by the CPT and SSC to accommodate the new size limit strategy in the eastern and western areas under Tier-4. The years selected for determination of biomass reference points is an action item for the May CPT meeting (see response to September 2010 CPT recommendations). As indicated, Tanner-snow crab hybrids are enumerated in survey data although it's uncertain as to the level of accuracy in this designation or its consistency over the time series. The frequency of hybrids in the catch data is unknown and it's not apparent how the catch data can be retrospectively partitioned into non-hybrid and hybrid catch.

We expect the effect of Tanner-snow crab hybrids in the Tanner crab catch data to be negligible as somatic growth would need to approximated that of Tanner crab to result in hybrids retained by the directed Tanner fishery at >= 138 mm cw. The largest size bin used in modeling snow crab is 130-135 mm cw plus group as snow crab larger than 135 mm cw are exceedingly uncommon. We examined the sizes of Tanner-snow crab hybrids observed in the survey data for 2004-2008 as an example. For these years, the largest and next largest size (mm cw) hybrid crab observed were: 2004 (126, 123), 2005 (133, 105), 2006 (138, 121), 2007 (133, 130), 2008 (149, 135). Only in 2008 was a single hybrid crab observed larger than 138 mm cw. We'll examine extant survey data to more completely understand the potential impact of the occurrence of hybrid crab in the Tanner retained catch. The authors recommend that improved species-specific accounting protocols be implemented to reconcile stock assessments and catch reporting.

<u>June 2010 Meeting</u>:
In their review of the crab SAFEs and OFLs, the SSC made the following general comments on eastern Bering Sea Tanner crab:

- *Tanner crab abundance has fallen below the MSST which will require a rebuilding plan to be developed. A stock assessment model is under development but not yet ready for review. The plan is to get CPT and SSC review in September / October 2010 for use in the rebuilding plan to be drafted by May 2011. The SSC would like the authors to develop a model capable of handling two different minimum size limits in the eastern and western areas as the BOF may take such action; this might be beneficial for optimal harvesting.*
- *Lacking a stock assessment model, stock status determination continues to be based on the trawl survey. This year the revised survey estimates corrected for survey net width were used for the first time. Final determination will be made after the summer survey.*
- *The SSC concurs with the CPT that the stock is in Tier 4, given the survey series and an estimate of M, and with the use of a default value for gamma of 1 to set OFL. The SSC requests that the authors and CPT reconsider the choice of years to be used in calculating B_{MSY}, currently 1969–1980. The issues of data quality and regime shift need to be more fully addressed. The SSC commented that it's possible that the generally warmer Bering Sea is in a new regime, with more groundfish predators (e.g., cod) and competitors (e.g., flatfish), which has caused a change in Tanner crab productivity. Two options might be to extend the time period to the current time or start the time period later, depending on identification of the shift.*
- *The CPT recommended that the text for OFL calculation should be revised to represent what was actually done. It might be helpful for the CPT to elaborate on what was incorrect in the SAFE, so that the authors can make the appropriate changes.*

As shown in this assessment, the 2009/10 Tanner crab stock is below the MSST and determined to be overfished. A length-based stock assessment model is in development. The current goal is to complete model development and have it approved by the CPT in May 2012 and by the SSC in June 2012 for application in 2012/13 OFL-setting. If approved in 2011, the model would be available for use in developing the rebuilding plan. The timing of the start of the two year time frame for implementing the rebuilding plan by the Council is unclear at the time of this assessment. Neither has it been specified when the draft the rebuilding plan will be required, nor the dates of the plan amendment process regarding review, comment and finalization of the rebuilding plan by the Council.

The CPT will discuss the requirements of for draft completion at their May 2011 meeting and the authors will have a better understanding of the requirements of model development once the elements of the rebuilding plan are identified and the required benchmark dates identified.

At the May 2010 meeting, the CPT considered genetic evidence presented in support of partitioning the EBS Tanner crab population into two stocks east and west of 166^{o} W longitude. The CPT found this evidence lacking. The authors have found no evidence to support the argument that the eastern Bering Sea shelf is member to two distinct, non-intermixing, non-interbreeding stocks of Tanner crab in which the linked population and fisheries dynamics are bifurcated east and west of 166^{o} W longitude. The authors will consider approaches to handle different minimum size limits for the eastern and western areas consistent with the total catch OFL that may underlie optimum harvest strategies.

The authors agree that the stock status determination is based on trawl survey biomass and that these estimates will be based on revised bottom trawl survey data using measured net widths beginning in 2010/11.

The authors agree that Tanner crab is a Tier-4 stock in which the OFL is based on M using a gamma of 1.0. As a general observation, we agree that over the time period 1960s to present, there has been an apparent shift in the eastern Bering Sea from a more decapod-dominated ecosystem to a more teleost-dominated ecosystem currently. We've found no evidence, however, of a change in Tanner crab productivity over this period, nor of changes in reproductive dynamics or life-history characteristics which would reveal temporal changes in recruitment success resulting from the "*generally warmer Bering Sea*". The authors have shown (Rugolo and Turnock 2010) that the historical patterns of fishery exploitation on MMB from the late 1960s to the present exceeded rates that we would deem biologically reasonable for this stock. Exploitation rates on MMB rose in the late 1970s and peaked at 0.69, then declined with the collapse in stock biomass through the mid-1980s, then rose again to 0.45 following the build up in the stock in the late1980s to early-1990s. At these rates, the Tanner crab stock would not be expected to persist at sustainable levels in the short-term, nor modulate around B_{MSY} in the long-term.

If there have been effects of "*generally warmer*" ambient temperatures on Tanner crab productivity or from increased competition and predation on survival, empirical data have not shown these effects nor would the magnitude of such effects, if any, be readily separable from the effects of excessive fishing mortality on the stock. The former range of years (1969-1980) used for estimating B_{REF} included a five year period (1976-1980) of sharply declining and low male mature biomass. Inclusion of these years was required by the SSC in 2009. The authors do not believe that these that these five years represent levels of male mature biomass that, if fished at F_{MSY}, would yield MSY to the fishery. The revised range of years (1974-1980) for estimating B_{REF} also includes this five years of declining and low male mature biomass. Extending the time period to the current time would include time periods where the stock had collapsed and the fishery closed due to conservation concerns. The time period from 1980 to present is characterized by exceedingly low and unsustainable levels of stock biomass, punctuated by periods (late-1970s to mid-1980s, and early-1990s to present) of collapsed stock. Inclusion of years in which stock biomass had fallen to levels requiring fishery closures in an estimate of B_{REF} would be inconsistent with the tenet of selection of a range of years that represent the stock living dynamically at B_{MSY} from being fished at rates approximating F_{MSY}, and thereby yielding MSY to the fisheries.

The OFL calculation in this and previous assessments represents what is done. In this assessment, the authors revised Section E.2 (Model Description) to clarify the computational logic used in OFL-setting.

2. CPT Comments:

<u>September 2010 Meeting:</u>

In their review of the 2010 stock assessment, the CPT made the following recommendations related to Tanner crab rebuilding plan and stock assessment:

- *The rebuilding plan will need to consider and address possible effects of groundfish fisheries and may need to recommend controls on the mortality to EBS Tanner crab due to bycatch in the groundfish fisheries.*

- *The time period for computing B_{REF} should be reviewed and evaluated in the rebuilding plan; options for that time period should be considered and evaluated for review by the SSC. The CPT received public testimony recommending a reconsideration of the validity of the period used to compute B_{REF} in the September 2010 assessment (i.e., 1969-1980).*

The authors agree that the Tanner crab rebuilding plan must address the effects of bycatch from the groundfish fisheries. To the extent that non-directed stock losses may affect stock recovery, the plan may need to recommend controls on the mortality of Tanner crab resulting from these fisheries.

The time period of years selected for determining the biomass reference point is an action item for the May CPT meeting. Based on the outcome of the Crab Modeling Workshop (February 2011) and recommendations of the SSC (March 2011), the 1969-1973 survey biomass estimates will be excluded from the analysis. By this change, the revised time period for computing B_{REF} from 1974-1980 resulting in B_{REF}=83.30 thousand t. The authors recommend this result.

The authors listened to the public testimony at the September 2010 CPT meeting that questioned the validity of the 1969-1980 period for computing B_{REF}. Although the CPT minutes don't elaborate, the stated criticism was that the current environmental regime the eastern Bering Sea has resulted in a different production potential for the Tanner crab stock and that there should be no expectation that the stock could recover to levels observed during this period. This hypothesis is speculative and we suggest that it's incumbent on its advocates to provide the CPT results of an analysis that gives clear and convincing evidence for its support. Otherwise, we consider it capricious to employ inference from presumptive argument to lower the threshold biomass considered to represent a rebuilt stock particularly given the importance of this decision to the health of the ecosystem and the fisheries.

The testimony that the Tanner crab stock should not be expected to recover to levels observed prior to 1980 is inconsistent with the data. If we consider stock performance measured as MMB at the time of the fishery (i.e., prior to catch extraction), that mean quantity over the revised time period (1974-1980) for computing B^*_{REF} is 123.2 thousand t (se=24.8). Even after experiencing excessive rates of exploitation prior to 1980 and the presumptive effects of the so-called '*1976 environmental regime change*', the stock recovered to an average 1989-1992 MMB at fishery = 94.0 thousand t (se=0.9), or 76.3% of 123.2 thousand t. Extending this average one year on either side of the mode to 1988-1993, the mean MMB at fishery was 81.1 thousand t (se=8.2), or 65.8% of B^*_{REF}. Recruits which gave rise to this mode of MMB in the late-1980s to early-1990s were from cohorts produced in the early-1980s – thus, after the so-called '*1976 environmental regime change*' and any presumed change in reproductive potential. The Tanner crab stock demonstrated the ability to recover to greater than 75% of this reference biomass despite the collective effects of excessive exploitation and the theorized environmental regime change.

We observe that the current measure of B_{REF} employed for EBS crab stocks (i.e., MMB at mating) exempts excessive fishery exploitation in the measure of reproductive biomass since MMB at mating is tabulated after the extraction of the catch. The authors propose an alternative B_{REF} measure which adjusts for exploitation in excess of F_{MSY}. Using the 1974-1980 mean MMB at the time of the fishery (B^*_{REF}= 123.2 thousand t) as a proxy for B_{MSY}, if exploited at F_{MSY}=M=0.23 would yield a mean MSY catch of 28.3 thousand t. Extracting this catch from B^*_{REF} gives an alternative proxy estimate of B_{MSY}=94.9 thousand t over 1974-1980 compared to 83.3 thousand t based on MMB at mating. The current B_{REF} based on MMB at mating is a biased low measure of reproductive potential in instances where fishery removals exceed those estimated using F_{MSY}. If recruitment was maintained despite excessive removals, the extent of this bias is proportional to the magnitude of the catch in excess of MSY.

As a general observation, we agree that from the 1960s to present, there has been an apparent shift in the eastern Bering Sea from a more decapod-dominated ecosystem to a more teleost-dominated ecosystem currently. We've not found evidence of a change in Tanner crab productivity over this period, nor of changes in reproductive dynamics or life-history characteristics which reveal temporal changes in recruitment resulting from the purported '*1976 environmental regime change*'. The authors have shown (Rugolo and Turnock 2010) that the historical patterns of fishery exploitation on MMB from the late 1960s to the present exceeded rates that we would now deem biologically reasonable for this stock. Exploitation rates on MMB rose in the late 1970s and peaked at 0.69 in 1978, then declined with the collapse in stock biomass through the mid-1980s, then rose again to 0.45 and followed the build up in the stock in the late-1980s to early-1990s. The exploitation rate on legal male biomass in 1978 was estimated in this assessment was 0.94. At these rates, the Tanner crab stock would not be expected to persist at sustainable levels in the short-term, nor modulate around B_{MSY} in the long-term.

If there have been effects of a change in environmental regime on Tanner crab productivity or from increased competition and predation on survival, empirical data have not shown those effects. Neither would the magnitude of those effects, if any, be easily separable from those of excessive fishing mortality on the stock. The revised range of years (1974-1980) used to estimate B_{REF} includes a five year period (1976-1980) of sharply declining and low male mature biomass. Inclusion of these five years was required by the SSC in 2009. The authors do not believe that these that these five years represent levels of mature male biomass that, if fished at F_{MSY}, would yield MSY to the fishery. Extending the time period to present would include time periods where the stock had collapsed and the fishery closed due to conservation concerns. The time period from 1980 to present is characterized by exceedingly low and unsustainable levels of stock biomass, and punctuated by periods (late-1970s to mid-1980s, and early-1990s to present) of collapsed stock. Inclusion of years in which stock biomass had fallen to levels requiring fishery closures in an estimate of B_{REF} would be inconsistent with the tenet of selection of a range of years that represent the stock living at B_{MSY}, being fished at rates approximating F_{MSY}, and thereby yielding MSY to the fisheries.

May 2010 Meeting:
In their stock assessment review, the CPT made the following comments concerning the Tanner crab Tier-4 stock assessment:

- *The current assessment estimates a likely upper limit on MMB at time of mating. Final results depend on fishery performance. It is estimated from the 2009 survey that the stock was below the MSST at that time, and the catches during the 2009/10 fishery will have led to the MMB at mating in 2010 being lower. A formal determination of the stock being overfished will occur with the Fall 2010 assessment.*

The CPT had the following recommendations for the authors:

- *Include CV's with point estimates in the tables.*
- *Determine whether groundfish discards are based on all groundfish fisheries or only trawl fisheries.*
- *Revise the text for OFL calculation (Eq. 3 and 4) to represent what was actually done.*
- *Remove Appendix A as it came from a prior assessment.*
- *Provide the September meeting with a summary of progress with the new model. The CPT may recommend that additional planning meeting may be necessary depending on progress given the necessity of this model for the rebuilding plan.*

In this document, the authors provide a final assessment of the status of the 2009/10 Tanner crab stock based on estimated MMB at mating in mid-February 2010. The 2009/10 stock is below the status determination criterion indicative of an overfished stock. The authors made best attempts to address the recommendations of the CPT in this assessment. Developing the time-series of CVs for metrics tabled in this document has proven more involved than anticipated given the change in survey data based on measured net widths used in this assessment. We'll continue to make best efforts to develop these data and work with the Shellfish Assessment Program who is lead concerning data verification and re-estimation of the historical time series. As we previously reported to the CPT, groundfish discards are based on all groundfish fisheries. The OFL calculation in this and previous assessments represents what is done. The authors revised Section E.2 (Model Description) to clarify the computational logic used in OFL-setting. Appendix A is removed in this assessment. The authors will discuss progress on the new model at the September 2010 meeting.

C. Introduction

1. Scientific Name and General Distribution

Tanner crab *Chionoecetes bairdi* originally described by Rathbun (1924) is one of five species in the genus *Chionoecetes*. The taxonomic classification attributable to Garth (1958) has been revised (see McLaughlin et al. 2005) to include name changes for a number of hierarchical categories:

Class	Malacostraca
Order	Decapoda
Infraorder	Brachyra
Superfamily	Majoidea
Family	Oregoniidae
Genus	Chionoecetes

The common name for *C. bairdi* of "Tanner crab" (Williams et al. 1989) was recently modified to "southern Tanner crab" (McLaughlin et al. 2005). Prior to this change, the term "Tanner crab" has also been used to refer to other members of the genus, or the genus as a whole. Hereafter, the common name "Tanner crab" will be used in reference to "southern Tanner crab".

Tanner crabs are found in continental shelf waters of the north Pacific. In the east, their range extends as far south as Oregon (Hosie and Gaumer 1974) and in the west as far south as Hokkaido, Japan (Kon 1996). The northern extent of their range is in the Bering Sea (Somerton 1981a) where they are found along the Kamchatka peninsula (Slizkin 1990) to the west and in Bristol Bay to the east.

In the eastern Bering Sea (EBS), the Tanner crab distribution may be limited by water temperature (Somerton 1981a). *C. bairdi* is common in the southern half of Bristol Bay, around the Pribilof Islands, and along the shelf break where water temperatures are generally warmer. The southern range of the cold water congener the snow crab, *C. opilio*, in the EBS is near the Pribilof Islands (Turnock and Rugolo 2010). The distributions of snow and Tanner crab overlap on the shelf from approximately 56° to 58°N, and in this area, the two species hybridize (Karinen and Hoopes 1971).

2. Stock structure

Tanner crabs in the EBS are considered to be a separate stock distinct from Tanner crabs in the eastern and western Aleutian Islands (NPFMC 1998)**.** The unit stock is that defined across the geographic range of the EBS continental shelf, and managed as a single unit. Somerton (1981a) suggests that clinal differences in some biological characteristics may exist across the range of the unit stock. Somerton's conclusions are limited since he did not recognize that terminal molt at maturity is a characteristic of this species, nor consider stock movement with ontogeny. Thus, biological characteristics estimated based on comparisons of length frequency distributions across the range of the stock, or on modal length analysis over time are confounded by these omissions.

Despite the custom of setting management controls for this stock east and west of 166^{o} W longitude, the unit stock of Tanner crab in the EBS comprises crab throughout the geographic range of the NMFS trawl survey. No evidence supports partitioning the unit stock into discrete, non-interbreeding, non-mixing sub-populations which can be assessed and managed separately. Given requisite understanding of the geographic fidelity of the stock over its range and its availability to the fisheries, partitioning the total catch OFL may be possible to allow setting TACs or issuing of IFQs for the Eastern and Western District fisheries consistent with the total catch OFL.

D. Data

1. The Survey (2010 SAFE – To Be Updated)

The NMFS conducts an annual trawl survey in the EBS to determine the distribution and abundance of commercially-important crab and groundfish fishery resources (Chilton et al. 2010). The survey has been conducted since 1968 by the Resource Conservation and Engineering (RACE) Division of the Alaska Fisheries Science Center. It's been conducted annually since 1975 when it also expanded into Bristol Bay and the majority of the Bering Sea continental shelf. Since 1988, 376 standard stations have been included in the survey covering a 150,776 nm^2 area of the EBS with station depths ranging from 20 to 150 meters depth. The annual collection of data on the distribution and abundance of crab and groundfish resources provides fishery-independent estimates of population metrics and biological data used for the management of target fishery resources. Crustacean resources targeted by this survey are red king crab (*Paralithodes camtschaticus*), blue king crab (*P. platypus*), hair crab (*Erimacrus isenbeckii*), Tanner crab (*Chionoecetes bairdi*) and snow crab *(C. opilio*). The sampling methodology specifies the majority of tows made at the centers of squares defined by a 20 x 20 nmi (37 x 37 km) grid (Figures 1 and 2). Near St. Matthew Island and the Pribilof Islands, additional tows were made at the corners of squares that define high density sampling strata for blue king crab and red king crab.

The eastern otter trawl with an 83 ft (25.3 m) headrope and a 112 ft (34.1 m) footrope has been the standard gear since 1982. Each tow was approximately 0.5 h in duration towed at 3 knots, and conducted in strict compliance with established NMFS groundfish bottom trawl protocols (Stauffer 2004). Crabs are sorted by species and sex, and then a sample of the catch measured to the nearest millimeter to provide a size-frequency distribution. Derived population metrics are indices of relative abundance and biomass and do not necessarily represent absolute abundance or biomass. They are most precise for large crabs, and are least precise for small crabs due to gear selectivity, and for females of some stocks due to differential crab behavior.

Estimates of Tanner crab stock biomass, population metrics and length frequencies from the trawl survey used in this assessment were based on area-swept calculations using measured net widths spreads for 1969-2010. Survey for 1969-1973 are not used in the OFL analysis. Previous survey data for 1969, 1970 and 1972-1975 for males and 1974-1975 for females were extracted form historical International Pacific Fisheries Commission (INPFC) documents. Figures 1 and 2 present the distribution catch-per-unit effort by tow for legal males, sublegal males, ovigerous females, barren mature females and immature females from the 2010 survey. The highest abundance of males and females occurs from 163 to 170 degrees W longitude with the distinction that males also reveal moderate levels of abundance in the area of the Pribilof Islands. Areas of highest abundance of male and female Tanner crab in 2010 occurred from southwestern Bristol Bay northeastward to the Pribilof Islands. Figures 13 and 14 show the abundance by carapace width estimated from the survey for male and female Tanner crab.

Stock Biomass

Tanner crab male mature biomass (MMB) and legal male biomass (LMB) exhibited periods of peak biomass in the early to mid-1970s and the early to mid-1990s (Table 5, Figure 4b). LMB and MMB estimates in this analysis date to 1974. The components of MMB and LMB at the time the survey, at the time of the fishery and at the time of mating are shown in Table 5 and Figure 6. The historical bimodal distribution in male biomass (Figure 4) is also reflected in the pattern of the directed fisheries with peak modes in the mid-1960s through mid-1970s and in the late-1980s to early-1990s (Table 5, Figure 5), and collapsed stock status following those modes. MMB at the survey revealed an all-time high of 257.0 thousand t in 1975, and a second peak of 108.3 thousand t in 1991 (Figure 4). From the late-1990s through 2008, MMB rose at a moderate rate from a low of 10.4 thousand t in 1997 to 73.6 thousand t in 2007 before falling to 32.1 thousand t in 2010. Under the former BSAI King and Tanner Crab fishery management plan (NPFMC 1998) and overfishing definitions, the Tanner crab stock was above the B_{MSY} level indicative of a restored stock for the second consecutive year in 2007 and declared rebuilt. Tanner crab MMB at the time of mating in mid-February 2010 fell below the MSST resulting Tanner crab being declared overfished in September 2010.

In 2010, Tanner crab MMB at the time of the survey was estimated at 32.08 thousand t representing a 9.1% decrease relative to 2009. Mature male abundance fell 9.4% relative to 2009 and legal males were sparsely and patchily distributed throughout the survey range with regions of highest abundance in southwestern Bristol Bay and the Pribilof Islands. Legal males were sparsely and patchily distributed throughout the survey range with an area of moderate abundance in southern Bristol Bay and an area of high density near the Pribilof Islands (Figure 1). The abundance index for legal male Tanner crab in both districts combined increased 13.7% to 8.0 million crabs between 2009 and 2010 owing largely to a high-density station in the area of the Pribilof Islands. Legal-sized males represent only a small portion (3.7%) of total male abundance in 2010. Legal males were distributed 56.1% (4.5 million crabs) east and 43.9% (3.5 million crabs) west of 166^o W longitude which compared to 53.3% and 46.7%, respectively in 2009. The abundance index (39.2 million crabs) for pre-recruit male crabs (110-137 mm cw) showed a 15.4% decrease, and the index of 167.3 million small males (< 110 mm cw) increased 13.9% relative to 2009 for all areas combined (Figure 9). Pre-recruit crab in 2010 were widely distributed across the range of the survey from southern Bristol Bay northwest to St. Matthew Island (Figure 1). Regions of highest abundance of pre-recruit males in 2010 were seen in southwestern Bristol Bay and the surrounding area of the Pribilof Islands (Figure 1). Total male abundance increased 8.5% between 2009 and 2010 which was largely driven by the increase in small males (Figure 9).

Comparison of the male size frequency distributions between 2006 and 2010 revealed a decline in male abundance above 70 mm cw between 2009 and 2010, and a relatively increasing percentage of old shell crabs in the mature male stock (Figures 10 a-e). The 2006 male size-frequency revealed a prominent mode in the 70-75 mm cw range which persisted to 2007 at 90 mm cw (Figures 10a and 10b). However, this mode is absent from the 2008, 2009 and 2010 survey length frequency distributions (Figures 10 c-e and 12a). The recruit mode (20-40mm cw) seen in 2009 (Figure 10 d) grew to 30-50 mm cw in 2010 (Figure 10 e). Among all male Tanner crab in 2010, 19.3% were old shell in all categories combined, and 80.7% were comprised of molting, new-soft and new-hard shell (78.6%) categories (collectively, new shell males). Among legal-sized males, 42.2% were old shell all categories combined and 49.3% were new-hard shells. The decline in male abundance in 2010 above 70 mm cw coupled with the relatively high percentage of old and very old shell males in the mature stock is an issue of concern regarding future reproductive potential of this stock.

Large female (>=85 mm cw) Tanner crab in the combined Eastern and Western Districts revealed a substantial 49.7% decrease in abundance relative to 2009, and these were comprised of 79.5% old shell females (Figure 9). Among all female Tanner crab in 2010, 15.5% were collectively old shell and 84.5% comprised of molting, new-soft and new-hard shell (82.7%) categories (collectively, new shell females). The small female (<85 mm cw) abundance index increased by 13.8% to 150.3 million crabs relative to 2009. Total 2010 female abundance (164.1 million crabs) increased 8.5% which was largely influenced by the increase in small females <85 mm cw, and the total abundance of male and female combined (378.6 million crabs) increased 9.3% over that in 2009 driven by the increase in both small male and small female crabs (Figure 9). Ovigerous females were distributed from southern Bristol Bay at relatively highest abundance northwestward to south of St. Matthew Island with an area of moderate density near the Pribilof Islands (Figure 2). Immature female Tanner crab displayed a similar distribution to mature females although they were slightly more densely distributed relative to matures along the southeast-northwest cline from southwestern Bristol Bay, north of the Pribilof Islands to west and south of St. Matthew Island (Figure 2). The survey length frequency distributions of female Tanner crab from 2006-2010 revealed consistently declining abundance across the size modes and the general failure of modes of abundance to persist inter-annually (Figures 11a-e). The prominent length mode between 65-75 mm cw seen in 2006 did not persist in expected levels of abundance from 2007 through 2010 and revealed consistently declining abundance. The mode of mature females in 2008 at 75 mm cw declined in abundance in 2009 and is comprised of increasing percentages of old and very old shelled females. The moderate mode of female abundance above 60 mm cw seen in 2009 (Figure 11 d), which was dominated by old and very old shell females, declined substantially in 2010 (Figure 11 e). A modest mode of new shell recruits seen in 2009 at 25-30 mm cw persists in 2010 at 35-50 mm cw and new shell females dominate the 2010 length frequency distribution below 65 mm cw. A large portion of mature female Tanner crab 75 mm cw and larger in 2010 are comprised of old shell females (Figure 11e). As seen for male Tanner crab, female abundance above 60mm cw declined in 2010 (Figure 11e).

2. The Fishery

Management Unit

Fisheries have historically taken place for Tanner crab throughout their range in Alaska, but currently only the fishery in the EBS is managed under a federal fisheries management plan (NPFMC 1998). The plan defers certain management controls for Tanner crab to the SOA with federal oversight (Bowers et al. 2008). The state manages Tanner crab based on registration areas divided into districts. Under the plan, the state can adjust or further subdivide districts as needed to avoid overharvest in a particular area, change size limits from other stocks in the registration area, change fishing seasons, or encourage exploration (NPFMC 1998).

The Bering Sea District of Tanner crab Registration Area J (Figure 3) includes all waters of the Bering Sea north of Cape Sarichef at 54° 36' N lat. and east of the U.S.-Russia Maritime Boundary Line of 1991. This district is divided into the Eastern and Western Subdistricts at 173° W longitude. The Eastern Subdistrict is further divided at the Norton Sound Section north of the latitude of Cape Romanzof and east of 168° W longitude and the General Section to the south and west of the Norton Sound Section (Bowers et al. 2008).

In March 2011, the Alaska Board of Fisheries approved a new minimum size limit strategy for Tanner crab that will be in effect for the 2011/12 fishery. The previously minimum legal size limit was 5.5" (138 mm cw) throughout the Eastern Subdistrict. The new regulations established different minimum size limits east and west of 166° West longitude. That for the fishery to the east will be 4.8" (122 mm cw), and that to the west will be 4.4" (112 mm cw). The industry may self-impose retention of crab above 5.5" (138 mm cw) and 5" (127 mm cw) east and west of 166° West longitude, respectively.

The domestic Tanner crab (*C. bairdi*) pot fishery rapidly developed in the mid-1970s (Table 2, Figures 5). For stock biomass and fishery data tabled in this document, we adopted the convention that 'year' refers to the survey year, and fishery data are those subsequent to the survey, through prior to the survey in the following year. Other notation is explicit – e.g., 2008/09 is the 2008 summer survey and the winter 2009 fishery. United States landings were first reported for Tanner crab in 1968 at 0.46 thousand t taken incidentally to the EBS red king crab fishery (Table 2). Tanner crab was targeted thereafter by the domestic fleet and landings rose sharply in the early-1970s, reaching a high of 30.21 thousand t in 1977 (Table 2, Figure 5). Landings fell precipitously after the peak in 1977 through the early 1980s, and domestic fishing was closed in 1985 and 1986 as a result of depressed stock status. In 1987, the fishery reopened and landings rose again in the late-1980s to a second peak in 1990 at 18.19 thousand t, and then fell sharply through the mid-1990s (Figure 5). The domestic Tanner crab fishery closed between 1997 and 2004 as a result of severely depressed stock condition. The domestic Tanner crab fishery re-opened in 2005 and has averaged 0.77 thousand t retained catch between 2005-2009/10 (Table 2). Landings of Tanner crab in the foreign Japanese pot and tangle net fisheries were reported between 1965-1978, peaking at 19.95 thousand t in 1969 (Table 2, Figure 5). The Russian tangle net fishery was prosecuted between 1965-1971 with peak landings in 1969 at 7.08 thousand t. Both the Japanese and Russian Tanner crab fisheries were displaced by the domestic fishery by the late-1970s.

Discard and bycatch losses of Tanner crab originate from the directed pot fishery, non-directed pot fisheries (notably, for snow crab and red king crab), and the groundfish fisheries (Table 3). Discard/bycatch mortalities were estimated using post-release handling mortality rates (HM) of 50% for pot fishery discards and 80% for groundfish fishery bycatch (NPFMC 2008). Total Tanner crab discard and bycatch losses by sex are shown in Table 3 for 1965-2009. The pattern of total discard/bycatch losses is similar to that of the retained catch (Table 2). These losses were persistently high during the late-1960s through the late-1970s; male losses peaked in 1970 at 20.17 thousand t (Table 3). A subsequent peak mode of discard/bycatch losses occurred in the late-1980s through the early-1990s which, although briefer in duration, revealed higher losses for males than the earlier mode, peaking at 22.82 thousand t in 1990. From 1965-1975, the groundfish fisheries contributed significantly to total bycatch losses, although the combined crab pot fisheries are the principal source of contemporary non-retained losses to the stock (Table 3). Total Tanner crab retained catch plus non-directed losses of males and females (Table 4, Figure 4a) reflect the performance patterns in the directed and non-directed fisheries. Total male catch rose sharply with fishery development in the early-1960s and reveals a bimodal distribution between 1965 and 1980 with peaks of 47.48 thousand t in 1969 and 52.30 thousand t in 1977 (Table 4, Figure 4a). Total male catch rose sharply after the directed domestic fishery reopened in 1987 and reached a peak of 41.01 thousand t in 1990. Total male and female catch fell sharply thereafter with the collapse of the stock and the fishery closure in 1997.

Since re-opening of the domestic fishery in 2005, the relationship of total male discard/bycatch losses by all crab pot and groundfish fisheries combined to retained catch shifted relative to that between 1980-1996 (Tables 2 and 3). For 2005-2009, the ratio of total male discard losses to retained catch was 2.2, 1.8, 2.5,1.3, and 1.6 respectively, and averaged 1.9 (ser=0.2). The majority of these male losses are sub-legal sized crab, and the principal contributor to these non-retained losses is the non-directed snow crab fishery (Table 7a). This contrasts the pre-closure performance of the domestic fishery (1980-1996) which averaged 1.3 (se=0.1) pounds of non-retained male losses to each pound of retained catch. Corresponding ratios in terms of numbers of non-retained male losses to retained legal crab are more striking due to the contribution of sub-legal sized crab to total male discards. Discard and bycatch losses of male and female Tanner crab (Table 3) during the closures of the directed domestic fishery (1985-1986 and 1997-2004) reflect losses due to non-directed EBS pot fisheries and the domestic groundfish fisheries.

Exploitation Rates
The historical patterns of fishery exploitation on LMB and MMB were derived (Table 6, Figures 7a and 7b). The exploitation rate on LMB was estimated as the proportion of retained catch to LMB at the time of the fishery, while that on MMB as the proportion of total male catch to MMB at the time of the fishery. During 1974-2009, exploitation rate (μ) on LMB was highest in 1979 at 0.94 and second highest in 1981 at 0.54; thereafter, it fell with stock condition through the mid-1980s. LMB exploitation rates revealed a second prominent mode during 1989-1993, peaking at 0.46 in 1991 and averaging 0.44 during those five years (Table 6, Figure 7b). At these rates of exploitation on LMB, the Tanner crab was not expected to persist at maximum sustainable levels even in the short-term, nor modulate around B_{MSY} in the long-term. The pattern of μ on MMB from 1974-2009 reveals two analogous high periods: one associated with the high total catches in the mid-1970s to 1980; the other coincident with the mode of high catches in the late-1980s through early-1990s. Exploitation rates on MMB peaked at 0.69 in 1979 and at 0.44 in 1990, averaged 0.23 over 1986-1997 and followed the build up in stock biomass during that period.

3. Life-History

Reproduction
In most majid crabs, the molt to maturity is the final or terminal molt. For *C. bairdi*, it's now accepted that both males (Tamone et al. 2007) and females (Donaldson and Adams 1989) undergo terminal molt at maturity. Females terminally molt from their last juvenile, or pubescent, instar usually while being grasped by a male (Donaldson and Adams 1989). Subsequent mating takes place annually in a hard shell state (Hilsinger 1976) and after extruding their clutch of eggs. While mating involving old-shell adult females has been documented (Donaldson and Hicks 1977), fertile egg clutches can be produced in the absence of males by using stored sperm from the spermathacae (Adams and Paul 1983, Paul and Paul 1992). Two or more consecutive egg fertilization events can follow a single copulation using stored sperm to self-fertilize the new clutch (Paul 1982, Adams and Paul 1983), however, egg viability decreases with time and age of the stored sperm (Paul 1984).

Maturity in males can be classified either physiologically or morphometrically. Physiological maturity refers to the presence or absence of spermataphores in the gonads whereas morphometric maturity refers to the presence or absence of a large claw (Brown and Powell 1972). During the molt to morphometric maturity, there is a disproportionate increase in the size of the chelae in relation to the carapace (Somerton 1981a). While many earlier studies on Tanner crabs assumed that morphometrically mature male crabs continued to molt and grow, there is now substantial evidence supporting a terminal molt for males (Otto 1998, Tamone et al. 2007). A consequence of the terminal molt in male Tanner crab is that a substantial portion of the population may never reach the legal harvest size (NPFMC 2007).

Although observations are lacking for the EBS, seasonal differences have been observed between mating periods for pubescent and multiparous Tanner crab females in the Gulf of Alaska and Prince William Sound. There, pubescent molting and mating takes place over a protracted period from winter through early summer, whereas multiparous mating occurs over a relatively short period during mid April to early June (Hilsinger 1976, Munk et al. 1996, and Stevens 2000). In the EBS egg condition for multiparous Tanner crabs assessed between April and

July 1976 also suggested that hatching and extrusion of new clutches for this maturity status began in April and ended sometime in mid June (Somerton 1981a).

Fecundity
A variety of factors affect female Tanner crab fecundity including female size, maturity status (primiparous vs. multiparous), age post terminal molt, and egg loss (NMFS 2004a). Of these factors, female size is the most important, with estimates of 89 to 424 thousand eggs for EBS females 75 to 124 mm carapace width (cw) respectively (Haynes et al. 1976). Maturity status is another significant factor affecting fecundity with primiparous females being only ~70% as fecund as equal size multiparous females (Somerton and Meyers 1983). The number of years post maturity molt, and whether or not, a female has had to use stored sperm from that first mating can also affect egg counts (Paul 1984, Paul and Paul 1992). Additionally, older senescent females often carry small clutches or no eggs (i.e., barren) suggesting that female Tanner crab reproductive output is a declining function of age (NMFS 2004a).

The fraction of barren mature females by shell condition (Figure 15) and the fraction of mature females with clutches one-half full or less by shell condition (Figure 16) are shown. After 1991, 20-40% of new shell females brooded clutches less than or equal to 50% full, and in 2009 this number was approximately 23%. We developed a Tanner crab Egg Production Index (EPI) by female shell condition that incorporates observed clutch size measurements taken on the survey and fecundity by carapace width for 1976-2009 (Figure 17). Figure 17 also presents estimates of male and female mature biomass relative to the shell condition class EPIs in these years. Although male and female mature biomass increased after 2005, egg production does not increase proportionally to mature biomass (Figure 17).

Size at Maturity
Maturity at length (cw) schedules were estimated for male and female Tanner crab from extant NMFS trawl survey data. For females, we used egg and maturity code information collected on the survey from 1976-2009 to estimate the maturity curves for new shell females, and for the aggregate class of females all shell conditions combined. SM50%, for females all shell classes combined was estimated to be 68.8 mm cw, and that for new shell females was 74.6 mm cw. For males, data from the special collection of morphometric measurements taken to the 0.1 mm in 2008 on the NMFS survey was used to derive the classification rules between immature and mature crab based on chela allometry using the mixture-of-two-regressions analysis. We estimated classification lines between chela height and carapace width defining morphometric maturity for the unit Tanner crab stock, and for the sub-stock components east and west of 166^{o} West longitude. We then applied these rules to historical survey data from 1990-2007 to apportion male crab to the immature and mature populations. We examined and found no significant differences between the classification lines of the sub-stock components (E and W of 166^{o} W longitude), or between the sub-stock components and that of the unit stock classification line. SM50%, for males all shell condition classes combined was estimated to be 91.9 mm cw, and that for new shell males was 104.4 mm cw. By comparison, Zheng (1999) in development of the current SOA harvest strategy used knife-edge maturity of >79 mm cw for females and >112 mm cw for males. For harvest strategy purposes, mature females are defined as females >=80 mm cw (Bowers et al. 2008).

Somerton (1981b) noted differences in the size of Tanner crab female maturity across the range of the unit stock. As previously noted, Somerton's interpretations were limited since he did not recognize that terminal molt at maturity is a characteristic of this species, nor did he consider the pattern of ontogenous stock movement. Thus, maturity estimated based on comparisons of the proportions of mature individuals at length in any area, or on changes in the proportion of mature individuals at length over time are confounded by these omissions. Nonetheless, we report that for the 5 survey years from 1975 to 1979, east of 167° 15' W longitude, Somerton (1981a) estimated that the mean size of mature females ranged from 92.0 to 93.6 mm cw. West of that longitude, the size of 50% female maturity ranged from 78.0 to 82.0 mm cw. For male Tanner crab during the same survey years, he estimated size at 50% maturity was 117.0 mm cw and 108.9 mm cw east and west of 167° 15' W longitude, respectively.

Mortality

Due to a lack of reliable age information, Somerton (1981a) estimated mortality separately for individual EBS cohorts of juvenile (pre-recruits) and adult Tanner crab. Somerton postulated that because of net selectivity of the survey sampling gear, age five Tanner crab (mean cw=95 mm) were the first cohort to be fully recruited to the gear; he estimated an instantaneous natural mortality rate of 0.35 for this size class using catch curve analysis. Using catch curve analysis with two different data sets, Somerton estimated natural mortality rates of adult male crab from the fished EBS stock to range from 0.20 to 0.28. When using CPUE data from the Japanese fishery the estimated rate of M ranged from 0.13 to 0.18. Somerton concluded that M estimates of 0.22 to 0.28 estimated from models that used both the survey and fishery data were the most representative.

We examined empirical evidence for estimates of oldest observed age for male Tanner crab. Unlike its congener the snow crab, estimates of longevity of Tanner crab are lacking. We reasoned that longevity in a virgin population of Tanner crab would be analogous to that of the snow crab (Turnock and Rugolo 2010) given the analogues in population dynamic and life-history characteristics between these species, where longevity would be at least 20 years. Using 20 years as a proxy for longevity and assuming that this age represents the upper 98.5^{th} percentile of the distribution of ages in an unexploited population, M is estimated to be 0.23 (Hoenig 1983). If 20 years is assumed to represent the 95% percentile of the distribution of ages in an unexploited stock, M is estimated to be 0.15. The natural mortality rate (M) of EBS Tanner crab is set at 0.23 for assessing stock status and OFL-setting based on the current expectation of longevity of at least 15 y. This rate of M=0.23 is consistent with that used in Amendment 24 and its associated EA that established new overfishing definitions for crab stocks under the plan.

Growth and Age

Rugolo and Turnock (2010) derived the growth relationships for male and female Tanner crab using data collected in the Gulf of Alaska near Kodiak (Munk pers. comm., Donaldson et al. 1981). They also examined growth relationships developed by Zheng and Kruse (1999) (Figure 14). Somerton (1981a) estimated growth for EBS Tanner crab based on modal size frequency analysis of survey data assuming no terminal molt at maturity. Somerton's approach did not directly measure molt increments and his findings were confounded by not recognizing that inter-annual modal length progression was biased sicne male and female crab ceased growing after their maturity molt. We compared our growth per molt (gpm) relationships with those of Stone et al. (2003) for Tanner crab in southeast Alaska in terms of the overall pattern of gpm over the size range of crab. Initial results suggest that gpm is expressed by two distinct rates of growth for both males and females – a higher rate of growth to an intermediate size in the area 90-100 mm cw, coupled with a decrease in growth rate from that intermediate size thereafter. Such 'dog-leg' shaped growth curves are corroborated in work of Stone et al. (2003), Somerton (1981), Donaldson et al. (1981) and in the data of Munk. Work on the growth relationships is ongoing and we intend to examine curvilinear functions to fit the observed pattern of growth.

Somerton (1981a) studied growth of Tanner crab in the EBS and used modal length analysis to estimate growth per molt. Because of a lack data on smaller instars and no estimates of molt frequency, he combined size at age estimates from Kodiak crab (Donaldson et al. 1981) to construct a growth and age schedule for EBS Tanner crabs (Table 1). Radiometric ageing has suggested that age after the terminal molt to maturity may be 6-7 years (Nevisi et al. 1996). If mean age at maturity is 8-10 y, these results suggest that maximum age of an exploited stock is 14-17 y.

Weight at Length

We derived weight at length relationships for male, immature female and mature female Tanner crab based on special collections of length and weight data on the NMFS trawl survey in 2006, 2007 and 2009 (Figure 15). The fitted weight (kg)-length (mm cw) relationship for males of shell condition classes 2 (SC2) through class 5 (SC5) inclusive is: $W=0.00016(cw)^{3.136}$. Those for immature (SC2) and mature (SC2-SC4) females are, respectively, $W=0.00064(cw)^{2.794}$ and $W=0.00034(cw)^{2.956}$.

E. The Analytic Approach

1. History of Modeling Approaches

Tier-4 OFL Control Rule

Old Survey Data:

Tanner crab is managed as a Tier-4 stock. Through the 2009 assessment, the proxy B_{MSY} for management is the reference biomass (B_{REF})=86.80 thousand t MMB at the time of mating estimated as the average observed MMB_{mating} from the time period of 1969-80. As reported in Rugolo and Turnock (2009), Tanner crab MMB in 2009 declined to 39.74 thousand t and even at the time of the survey it was below the minimum stock size threshold MSST=$0.5B_{REF}$=43.04 thousand t. After accounting for all losses to the stock from the 2009/10 fisheries and natural mortality, the 2009/10 MMB at mating was 32.52 thousand t. This represented a ratio of 0.38 relative to B_{REF} which is below the limit that defines an overfished stock. The 2009/10 Tanner crab stock was deemed approaching an overfished condition as determined using stock relative to B_{REF} and MSST computed using survey MMB estimates based on the fixed 50 ft net width area-swept calculations.

New Survey Data:

Beginning with the 2010 assessment, all stock metrics, as well as overfishing definitions were based on survey estimates derived using the actual measured net width area-swept calculations. This resulted in changes in the historical time series data. Using the revised survey data, the B_{MSY} proxy B_{REF}= 83.80 thousand t and MSST=41.90 thousand t. After accounting for all losses to the stock from natural mortality and the 2009/10 fisheries, the 2009/10 MMB at the time of mating was 28.44 thousand t. This represented a ratio of 0.34 relative to B_{REF} which is below the limit that defines an overfished stock. The 2009/10 Tanner crab stock was determined to be overfished by NOAA Fisheries based on the 2010 stock assessment (Rugolo and Turnock 2010). For the 2011 assessment, B_{REF} estimated over the revised period (1974-1980) is 83.30 thousand t and MSST=41.65 thousand t.

MMB at the time of the 2010 survey declined 9.1% relative to 2009 and even at that time it was below the MSST. Thus, even under the zero retained catch strategy implemented in 2010/11, there will be no change in the 2010/11 stock status relative to the 2010 overfished determination. For example, between the 2010 survey and mating in 2011, if no natural mortality losses occurred, nor losses from the 2010/11 non-directed pot and groundfish fisheries, $MMB_{2010/11}/B_{REF}$ will be less than 0.34 estimated for the 2009/10 stock.

In the Environmental Assessment associated with Amendment 24 to the BSAI King and Tanner Crab fishery management plan (NPFMC 2008), Tier-4 stocks are characterized as those where essential life-history information and understanding are incomplete. Although a full assessment model cannot be specified for Tier-4 stocks or stock-recruitment relationship defined, sufficient information may be available for simulation modeling that captures essential population dynamics of the stock as well as the performance of the fisheries. Such modeling approaches can serve the basis for estimating the annual status determination criteria to assess stock status and to establish harvest control rules.

In Tier-4, a default value of M and a scaler Gamma (γ) are used in OFL setting. The proxy B_{MSY} represents the level of equilibrium stock biomass indicative of maximum sustainable yield (MSY) to fisheries whose mean performance exploits the stock at $F_{MSY.}$ For Tier-4 stocks, the proxy B_{MSY}, or B_{REF}, is commonly estimated as the average biomass over a specified period that satisfies the expectation of equilibrium biomass yielding MSY at F_{MSY}. It can also be estimated as a percentage of pristine biomass (B_0) of the unfished or lightly exploited stock where data exist. In Tier-4, the F_{OFL} is calculated as the product of γ and M, where M is the instantaneous rate of natural mortality. The Amendment 24 and its EA defines a default value of gamma=1.0. Gamma is allowed to be less than or greater than unity resulting in overfishing limits more or less biologically conservative than fishing at M. The specification of the scaler γ in the EA was intended to allow adjustments in the overfishing definitions to account for differences in the biomass measures used in EA simulation analyses. However, since Tier-4 stocks are information-poor by definition, the EA associated with Amendment 24 states that γ should not be set to a value that would provide less biological conservation and more risk-prone overfishing definitions without defensible evidence that the stock could support fishing at levels in excess of M. The resultant overfishing limit for Tier-4 stocks is the total catch OFL that includes expected retained plus discard and bycatch losses. For Tier-

4 stocks, a minimum stock size threshold (MSST) is specified; if current MMB is below MSST, the stock is overfished.

For Tier-4 stocks, the F_{OFL} is derived using and F_{OFL} Control Rule (Figure 8) according to whether current mature stock biomass metric (B) belongs to stock status levels a, b or c in the algorithm below. The stock biomass level beta (β) represents a minimum threshold below which directed fishing mortality is set to zero. The F_{OFL} Control Rule sets β=0.25. The parameter alpha moderates the slope of the non-constant portion of the control rule. For biomass levels where $\beta<B\leq B_{MSY}$, the F_{OFL} is estimated as a function of the ratio B/B_{MSY}. The value of M is 0.23 for eastern Bering Sea Tanner crab. In the analysis of Tier-3 for snow crab, *C. opilio,* and red king crab, *P. camtschaticus*, a B_{MSY} proxy reference value (B_{REF}) equal to 35% of the maximum spawning potential of the unfished stock was specified (Annon 2008, EA associated with Amendment 24). For Tier-4 stocks, a reference biomass value (B_{REF}) must is specified consistent with the expectation of a measure of equilibrium stock biomass (B_{MSY}) capable of yielding MSY to the fisheries operating at F_{MSY}.

Stock Status Level:		F_{OFL}:
a.	$B/B_{REF} > 1.0$	$F_{OFL} = \gamma M$
b.	$\beta < B/B_{REF} \leq 1.0$	$F_{OFL} = \gamma M\ [(B/B_{REF} - \alpha)/(1 - \alpha)]$
c.	$B/B_{REF} \leq \beta$	Directed Fishery F=0
		$F_{OFL} \leq F_{MSY}$

2. Model Description

In the Tier-4 OFL-setting approach EBS Tanner crab, various measures of stock biomass and catch components are integrated in the overfishing level determination. Here, we define each component and illustrate the approach used for OFL-setting based on these metrics.

A. Definition of Terms:

The following terms will be used in the illustration of our Tier-4 OFL-setting approach.

Let:

B_1	=	male mature biomass at the time of the survey
B_2	=	male mature biomass at the time of the fishery
B_3	=	male mature biomass at the time of mating
L_1	=	legal male biomass at the time of the survey
L_2	=	legal male biomass at the time of the fishery
L_3	=	legal male biomass at the time of mating
S_1	=	survival rate after 6 months of M = $e^{-M/2}$ from survey time to the nominal start of the fishery. (Not used in OFL-setting calculations).
S_2	=	survival rate from the time of the survey to mating (Δ=8 months) = $e^{-2M/3}$
M	=	instantaneous rate of natural mortality = 0.23
γ	=	scaler on M = 1.0
α	=	location parameter that determines intersection of sloping part of OFL control rule and the x-axis
β	=	minimum stock biomass threshold below which directed fishing is set to zero
B_{REF}	=	reference biomass value proxy for B_{MSY}
B_{MSY}	=	equilibrium biomass that yields maximum sustainable yield to the fisheries under an applied F_{OFL}
F_{OFL}	=	fishing mortality rate proxy for F_{MSY} that yields the Total Catch OFL (TC_{OFL}) using the F_{OFL} control rule
U_{OFL}	=	exploitation rate at the applied $F_{OFL} = (1-e^{-FOFL})$
TC_{OFL}	=	total catch overfishing limit corresponding to the F_{OFL} applied to male mature biomass at mating = $B_3S_2U_{OFL}$
C_1	=	total catch losses to MMB from retained + non-retained mortalities. Will equal TC_{OFL} if all projected catch losses are realized.
C_2	=	total catch losses to LMB from retained + non-retained mortalities
C_{RET}	=	retained catch of male mature biomass in the directed fishery in 2010/11

C_{3RET} = 3-year average (2007-09) retained catch of male mature biomass in the directed fishery
CO_{RET} = projected 2010/11 snow crab retained catch OFL
D_1 = discard mortality of MMB by the directed fishery
D_2 = discard mortality of MMB by the non-directed snow crab fishery
D_3 = discard mortality of MMB by the EBS groundfish fisheries
R_1 = 3-year average (2007-09) ratio of discarded mature male biomass per retained catch biomass in the directed fishery
R_2 = 3-year average (2007-09) rate of discarded mature male biomass per retained snow crab catch in the non-directed snow crab fishery
R_3 = 3-year average (2007-09) groundfish fishery discards of mature male biomass
HM_1 = post-release mortality rate for pot discarded crab (0.50)
HM_1 = post-release mortality rate for groundfish discarded crab (0.80)
TC_{PART} = residual part of the TC_{OFL} available to the directed fishery

B. OFL-Setting:

Determination of the total catch OFL (TC_{OFL}), F_{OFL}, resultant measures of stock biomass and the various catch components is a straightforward process given the F_{OFL} control rule and an estimate of MMB at the time of mating. The following prescription illustrates the logic of the computational approach, the arithmetic employed and formulae used in the estimation of all stock metrics an catch components:

1. Finding F_{OFL}:

Given B_{REF} and the estimate of mature male biomass at the time of mating, B_3, the overfishing limit F_{OFL} is found using the FOFL control rule algorithm:

$$F_{OFL} = \gamma M\,[(B_3/B_{REF} - \alpha)/(1 - \alpha)] \qquad (1)$$

2. Finding the TC_{OFL}:

Given the F_{OFL}, we can estimate the total catch OFL (TC_{OFL}) that results from applied fishing at the F_{OFL} on B_3 by:

$$TC_{OFL} = (B_1S_2U_{OFL}) \qquad (2)$$

$$= (B_1S_2(1-e^{-FOFL})) \qquad (3)$$

3. Finding B_3:

In the current directed fishery, catches occur mainly in January and February, and in March to a lesser extent. Retained catches coincide with the nominal time of mating (mid-February) eight months from the mid-point survey (mid-June), and span the nominal time of mating. We treat survival from survey to mating as a Type I process in which the stock is depreciated by M through mid-February then the catch is extracted instantaneously.

Thus, the estimate of male mature biomass at the time of mating (B_3) results from the combined survival of crab from the time of the survey to mating after natural morality, less the extraction of the total catch OFL (TC_{OFL}).

$$B_3 = (B_1S_2) - TC_{OFL} \qquad (4)$$

$$= (B_1S_2) - (B_1S_2U_{OFL}) \qquad (5)$$

$$= (B_1S_2) - B_1S_2(1-e^{-FOFL}) \qquad (6)$$

Replacing B_3 in (1) with equations (3) and (6) gives:

$$F_{OFL} = \gamma M\ [[[(B_1S_2) - B_1S_2(1\text{-}e^{-FOFL})]/B_{REF}] - \alpha]/(1 - \alpha)] \qquad (7)$$

Since there are unknowns on either side of the equality in equation (7), there is no analytical solution and it must be solved iteratively. This is because the F_{OFL} rate depends on the level of mature male biomass at mating (B_3) which, in turn, depends on the extracted $TC_{OFL.}$ Thus, we can't know the F_{OFL} until we extract the total catch OFL using the F_{OFL} control rule, and we can't estimate the TC_{OFL} until we have know the F_{OFL}. An iterative flow to solve for the F_{OFL} and TC_{OFL} is shown:

i. Initial guess at the F_{OFL-1} using B_1 in the F_{OFL} control rule. If B_1 is on the sloping part of the control rule, F_{OFL-1} will be too large by definition since $B_1>B_3$.
ii. Estimate TC_{OFL} using this F_{OFL-1}.
iii. Estimate B_3 using equation (4).
iv. Re-estimate the F_{OFL-2} using B_3 in the F_{OFL} control rule.
v. Test if F_{OFL-1}-F_{OFL-2} =0. If yes, set the final F_{OFL}=F_{OFL-2}. If no, depreciate F_{OFL-2} by a small increment resulting in F_{OFL-3}.
vi. Repeat using F_{OFL-3} in step ii to estimate the TC_{OFL} using F_{OFL-3} and end the iteration when the test in step v. is yes.

At the termination of the iteration, the final F_{OFL} for the OFL-setting will be known. Given that F_{OFL}, estimate the TC_{OFL} using equation (3) and the B_3 using equation (4).

4. Find Discard Catches in Non-Directed Fisheries:
Discard losses of male mature biomass are attributed to losses from the non-directed EBS crab pot fisheries and the groundfish fisheries. In practice, the discard catch components are estimated from past performance in the respective fisheries considered to be most representative of current conditions.

a. Non-Directed Pot Fishery Discard Mortalities:
Non-directed pot fishery discard losses to male mature biomass are principally attributed to the snow crab fishery and to the Bristol Bay red king crab fishery to a lesser extent. For example, the 2009/10 Tanner crab discards by the snow crab fishery comprised 94.8% of all pot discards from the snow crab and red king crab fisheries combined. In this analysis, we used data from the previous three fishing seasons (2007, 2008 and 2009) to estimate of the 3-year average ratio of Tanner crab mature male biomass discards in the snow crab fishery to snow crab retained catch (R_2) (Table 7b). Discard mortality of MMB by the non-directed snow crab fishery (D_2) in the 2010/11 TC_{OFL} is derived as the product of R_2 and the projected 2010/11 snow crab retained catch OFL (CO_{RET}) (Turnock and Rugolo 2010) given by:

$$D_2 = R_2\ CO_{RET}\ HM_1 \qquad (8)$$

b. Groundfish Fisheries Discard Mortalities:
Discard losses to male mature biomass resulting from bycatch in the groundfish fisheries (D_3) was estimated using the average groundfish bycatch of Tanner crab over 2007-09 (R_3) (Table 7c) supplied by the Alaska Regional Office, 08/26/10. We assumed that this average bycatch of Tanner crab would occur in the 2010/11 fishery. Reported bycatch are for males and females combined. The sex distribution of this bycatch is unavailable for this analysis. The proportion of males in the groundfish fisheries bycatch (P_M) was estimated assuming a sex ratio of 1:1 in the bycatch and apportioning the catch based on the ratio of mean weights of 120 mm cw male crab to 87.5 mm cw female crab resulting in a 60.2% v. 39.8% male to female split.

For all groundfish fishery discards, a post-release handling mortality rate of 0.80 was used (HM_2). Discard mortality of MMB by the groundfish fisheries (D_3) in the 2010/11 TC_{OFL} is given by:

$$D_3 \quad = R_3 \, P_M \, HM_2 \qquad (9)$$

5. Partial TC_{OFL} Available to Directed Tanner Crab Fishery:

Through this stage in the analysis, we've computed the total catch OFL (TC_{OFL}) for the 2010/11 fisheries which represents the threshold level of MMB catch beyond which constitutes overfishing. We have also computed the expected discard mortalities of MMB in the TC_{OFL} from the non-directed crab pot fisheries and the groundfish fisheries. These latter losses to male mature biomass can be considered fixed costs to MMB. They would occur whether or not a directed fishery is allowed, and are independent to an extent of the status of the Tanner crab stock (B_3) in 2010/11. They depend on the expected performance of the respective non-directed fisheries whose mean performance in terms of discards is not expected to change markedly in the 2010/11 fishing season. Projected discard mortalities depend on the relationship between Tanner male mature biomass and average discards being representative of current conditions – that, neither Tanner MMB nor the operations of the non-directed fisheries will change substantially so as make the relationships between recent 3-year performance and discards invalid.

6. Find Directed Tanner Crab Fishery Discard Mortalities:

The residual part (TC_{PART}) of the TC_{OFL} available to the directed fishery is estimated by extraction of the projected discard mortalities in the non-directed pot (D_2) and groundfish (D_3) fisheries by:

$$TC_{PART} = TC_{OFL} - (D_2 + D_3) \qquad (10)$$

However, since the directed Tanner fishery also contributes to discard mortalities of male mature biomass, the residual part (TC_{PART}) of the TC_{OFL} available to the directed fishery must be partitioned to allow for retained catch biomass (C_{RET}) and discard mortalities of male mature biomass (D_1). After accounting for discard losses by the directed fishery, the retained catch component of the OFL is by:

$$C_{RET} \quad = TC_{PART} - D_1 \qquad (11)$$

Discard losses of mature male biomass by the directed 2010/11 fishery (D_1) was estimated using data from the most recent three Tanner crab fisheries supplied by D. Pengilly, ADF&G (08/24/09) and B.Gaeuman (ADF&G, 07/02/10) (Table 7a). The average ratios of legal and sublegal male and female discards to the average retained catch in the 2007, 2008 and 2009 fisheries are used to project discard losses in the 2010/11 fishery. Here, R_1 is the 3-year average rate of discarded mature male biomass per retained catch biomass in the 2007-09 directed Tanner fisheries. For all pot discards, a post-release mortality rate of 0.50 was used (HM_1=0.50). Directed fishery discard losses (D_1) to male mature biomass is given by:

$$D_1 \quad = C_{RET} \, R_1 \, HM_1 \qquad (12)$$

Substituting for D_1 in equation (11) with equation (12), gives:

$$C_{RET} \quad = TC_{PART} - C_{RET} \, R_1 \, HM_1 \qquad (13)$$

At this stage in the analysis, TC_{PART} is known from equation (10). Also, known are R_1 and HM_1. However, C_{RET} is unknown and D_1 depends on C_{RET}. As with equation (7), there are unknowns on either side of the equality; there's no analytical solution and equation (13) which must be solved iteratively. This is readily accomplished by substitution of C_{RET} in equation (12) to estimate D_1 until the sum of $C_{RET} + D_1 = TC_{PART}$ which is known.

C. Exploitation Rates:

Exploitation rates on legal male biomass (μ_L) and mature male biomass (μ_M) at the time of the fishery are calculated as the ratio of total directed plus non-directed losses to legal male biomass (M_L) and mature male biomass (M_M) to the respective legal and mature male biomass at the time of the fishery (L_2 and M_2, respectively).

$$\mu_L = M_L/L_2 \qquad (14)$$

$$\mu_M = M_M/M_2 \qquad (15)$$

3. *Model Selection*

In May 2008, the CPT requested that the authors examine the feasibility of estimating $F_{35\%}$ for the Tanner crab stock using fishery selectivity. The SSC had recommended using fishery selectivity and maturity to estimate $F_{35\%}$ as the proxy F_{OFL}, and to estimate gamma as the ratio of $F_{35\%}$ to M. Results of that study are presented in Rugolo and Turnock (2009). In summary, fishery selectivity for Tanner crab used in the EA analysis were estimated on historical fishery performance data prior to the 1997 closure. We estimated selectivity for the contemporary fishery following its reopening in 2005 and found that the current selectivity for the directed and non-directed pot fisheries differed from those used in the EA. While it's desirable for Tier-4 stocks to employ the $F_{35\%}$ proxy for F_{MSY} where reliable data on fishery performance exist, the authors and SSC considered it premature to employ this approach for the Tier-4 Tanner assessment given these changes in performance observed in 2005-2007 versus those of the pre-1997 closure. Since the EA selectivity patterns no longer applied, their use in estimating $F_{35\%}$ and a factor in estimating gamma, may provide misleading and incorrect results in terms of management controls. The SSC concurred with the author's findings and recommended the $F_{35\%}$ not be used in OFL-setting since it could provide misleading results, and to set gamma=1.0.

In this assessment, gamma is set to 1.0, and discard mortalities from the directed and non-directed pot fisheries and the groundfish fisheries are included in OFL-setting. Even if pot fishery selectivities did not change after the reopening in 2005 relative to pre-1997, the EA simulations which suggest that $F_{35\%}$ may be a suitable F_{MSY} proxy for snow crab and Bristol Bay red king crab did not account for non-retained stock losses. Thus, it's uncertain what scaler of M is appropriate to relate M to full-selection $F_{35\%}$ rates in EA simulations. A further consideration in the estimation of gamma as the ratio of the EA $F_{35\%}$ to M is the fact that the MMB metric used in this assessment employs a maturity schedule, whereas the EA simulations employed knife-edge maturity at size. Thus, currency differences in the measure of reproductive biomass are potentially confounding.

The EA guidance prescribes that gamma should not be set to a level that would provide for more risk-prone overfishing definitions without defensible evidence that the stock could support levels in excess of M. Examination of the historical performance of the fishery (Figure 4a) and stock biomass (Figure 6) reveals that the Tanner crab stock has not been maintained in dynamic equilibrium over any sustained period, nor persisted in the face of exploitation rates (Table 6, Figures 7and 7b) that exceed levels we would consider biologically meaningful for this stock. The difference between fishery selectivity and maturity in EBS crab stocks has been suggested as a reason to allow gamma to exceed unity. Notwithstanding the technical challenges noted in estimating current fishery selectivity, this relies on theoretical population dynamic considerations in mature male biomass which are violated given the unique reproductive dynamic features of this stock (e.g., male-female size dependencies for successful copulation, male guarding and competition). Since a fundamental precept of precautionary fishery management is that the stock should not be exploited at a rate in excess of the F_{OFL}, we find no evidence that would justify a gamma in excess of 1.0 or fishing at an F_{OFL} rate greater than M on this stock.

4. Results (2010 SAFE – To Be Replaced)

In this assessment for OFL-setting for the 2010/11 fishery, the proxy B_{MSY} is B_{REF}=83.30 thousand t of MMB at the time of mating estimated from 1974-1980 inclusive. Formerly, B_{REF} was estimated over the period as requested by the SSC in 2009. The revised range of years (1974-1980) includes a five year period (1976-1980) of sharply declining and low male mature biomass. The authors do not consider that these that these five years represent levels of mature male biomass that, if fished at F_{MSY}, would yield MSY to the fishery. The production of stock biomass over 1974-1980 was affected by contemporaneous and antecedent high exploitation rates (Table 6, Figure 7a). This B_{REF} benchmark may underestimate the capacity of this stock to persist at B_{MSY} and provide maximum sustainable yield to the fisheries. The time period from 1980 to present is characterized by exceedingly low and unsustainable levels of stock biomass, and punctuated by periods (late-1970s to mid-1980s, and early-1990s to present) of collapsed stock and the imposition of a rebuilding plan by the NPFMC in 1999. During this period, the stock experienced exploitation rates in excess of current F_{MSY} estimates – at approximately 3M in the late-1970s, and 2M in the late-1980s preceding the collapses. During 1980-2009, the stock has not maintained itself at a level that could be reasonably construed as in dynamic equilibrium or at a level indicative of B_{MSY} capable of providing maximum sustainable yield to the fisheries. Inclusion of years in which stock biomass had fallen to levels requiring fishery closures in an estimate of B_{REF} would be inconsistent with the tenet of selection of a range of years that represent the stock living at B_{MSY}, being fished at rates approximating F_{MSY}, and thereby yielding MSY to the fisheries. The authors will revisit the choice of a proxy B_{MSY} with the development of the Tanner crab stock assessment model.

F. Calculation of the 2010/11 OFL (2010 SAFE – To Be Replaced)

The instantaneous rate of natural mortality, M, for Tanner crab is 0.23. Gamma is set=1.0. B_{REF}=83.80 thousand t, and MSST=41.90 thousand t.

For the 2010/11 Tanner crab fishery, we estimated the Total Catch OFL=1,612.1 t for males and females combined (Table 8). (Note, here we present the catch components in tonnes for clarity as the values in 1000 t for some components are small at one significant digit). Total losses to MMB in the 2010/11 Total Catch OFL are 1,445.5 t. Directed and non-directed discard losses to MMB in 2010/11 are estimated to be 46.4 t and 1,312.1 t, respectively. The retained part of the catch OFL of legal-sized crab is 87.0 t. The retained legal catch would comprise 6.4% of the total MMB losses. Thus, a significant component of MMB losses is attributed to non-targeted losses under current fishing practices.

Expected discard losses of female Tanner crab from the 2010/11 groundfish fishery and the directed pot fishery combined was estimated at 166.6 t. Estimated exploitation rates on LMB and MMB associated with these projected catches are 0.03 and 0.05 respectively.

The projected 2010 estimate of MMB at the time of mating is 26.07 thousand t after accounting for all retained and non-retained losses to MMB in 2010/11. Relative to B_{REF}, $MMB_{2010/11}/B_{REF}$=0.31. Under the OFL Control Rule, the 2010/11 F_{OFL}=0.05.

1. The 2011/12 OFL Apportioned E-W of 166^o W Longitude:

In March 2011, the BOF approved a new minimum size limit strategy for Tanner crab effective for the 2011/12 fishery. The new regulations established different minimum size limits east and west of 166° W longitude. That for the fishery to the east will be 4.8" (122 mm cw), and that to the west will be 4.4" (112 mm cw). The industry may self-impose retention of crab above 5.5" (138 mm cw) and 5" (127 mm cw) east and west of 166° W longitude, respectively.

We propose an approach to accommodate the new harvest regulations in the eastern and western areas under Tier-4. For Tier-4 stocks, the F_{OFL} is specified using an F_{OFL} control rule according to whether projected mature male biomass at mating belongs to one of three stock status levels. If MMB is greater than the minimum stock size threshold beta (β), the Total Catch OFL is derived as the product of MMB and the F_{OFL}. Since fishery selectivity is not factored in the Tier-4 process, the biomass of all mature males is used in the calculation of the Total Catch OFL. Thus, mature male crab of all sizes are vulnerable to the F_{OFL} and no additional adjustment is required for a minimum legal size limit in an area – i.e., mature male fishery selectivity=1.0 for all sizes.

A basis to apportion the Total Catch OFL into guideline harvest levels (GHLs) in the areas east and west of 166° W longitude would be the relative proportion of MMB in those areas estimated at the time of the survey. An assumption of this approach is that movement of crab from the time of the survey to the fishery is negligible or, alternatively, movement does not occur predominately from one area to the other. If so, a GHL_E and a GHL_W can be established with the following provisos:

1. The GHL_E and a GHL_W should not be considered area-specific total catch OFLs. They are guidelines for harvest to be taken under the size limit strategy implemented in each area.
2. The Total Catch OFL remains as the status determination criterion to assess whether overfishing has occurred. The sum of all stock losses to the east and west of 166^o W longitude will be gauged against the Total Catch OFL to assess overfishing.
3. In setting harvest policies for the new size limit strategy, it is recommended that the aim is not to exceed GHL_E and GHL_W. While there is no rule against setting GHL_E or GHL_W to the retained component of the Total Catch OFL, doing so would exploit MMB in that area at a rate that exceeds the F_{OFL} which could lead to unintended consequences on the reproductive potential of the stock as a whole.

Once the retained catch component (C_{RET}) of the total catch OFL is known from Eq. 13, the guideline harvest level for the area east of 166^o W longitude (GHL_E) and for the area west of 166^o W longitude (GHL_W) can be estimated as the product of C_{RET} and the proportion of MMB estimated in the respective areas ($P_{MMB\text{-}E}$, $P_{MMB\text{-}W}$) at the time of the survey by:

$$GHL_E = C_{RET} P_{MMB\text{-}E} \quad (16)$$

$$GHL_W = C_{RET} P_{MMB\text{-}W} \quad (17)$$

G. *Calculation of the 2010/11 ACL=ABC*

Background

The Environmental Assessment for amendments 38 and 39 to the management for the BSAI KTC stocks (NPFMC 2010) established methods by which the Council will set Annual Catch Limits (ACLs) to meet the requirements of the Magnuson-Stevens Act. The Act requires that ACLs be established based upon an acceptable biological catch (ABC) control rule that accounts for scientific uncertainty in the OFL such that ACL=ABC and the total allowable catch (TAC) and guideline harvest levels (GHLs) be set below the ABC so as not to exceed the ACL. ABCs must be recommended annually by the NPFMC's SSC.

Two methods for establishing the ABC control rule were considered: 1) a constant buffer approach where the ABC is set by applying a multiplier (M) to the OFL to meet a pre-specified buffer below the OFL; and 2) a variable buffer approach where the ABC is set based upon a pre-specified percentile (P*) of the distribution for the OFL that accounts for uncertainty in the OFL. P* is the probability that the ABC would exceed the OFL and overfishing occur. Two sources of uncertainty were used in setting the ABC for each stock: 1) σ_w, or within assessment uncertainty; and 2) σ_b, additional uncertainty, where total uncertainty σ_{total}=σ_w+σ_b. For all stocks, the EA recommended that some level of additional uncertainty be used in computing ABCs. A value σ_b =0.30 Tanner crab is recommended in the analysis.

Uncertainty in the Assessment

Additional uncertainty (σ_b) in this Tier-4 assessment is associated with estimates of stock biomass and the OFL which may be high relative to more well-studied BSAI crab stocks. Potential sources of additional uncertainty considered in formulating the ABC were: 1) pre-specified population dynamic parameters and life-history rates such as natural mortality, size-weight, maturity; 2) the assumption that F_{msy}=$F_{35\%}$ when applying the OFL control rule; and 3) the assumption that B_{msy} is represented by $B_{35\%}$ with an average biomass corresponding to MSY calculated over 1974-1980 using survey MMB at mating. The coefficient of variation (0.13) for the observed survey estimate of mature male biomass for 2010 is taken as the measure of within assessment uncertainty (σ_w).

Approach

The ABC=ACL for the 2011/12 fishery is estimated based on the Tier-4 control rule. Uncertainty was incorporated in the 2011/12 ABC in the estimation of survey biomass from the log-normal distribution incorporating σ_w=0.13 at two levels of additional uncertainty, σ_b=0 and σ_b=0.30 (σ_{total}=0.13 and σ_{total}=0.33, respectively), and in the estimation of B_{REF} from the distribution based on non-parametric bootstrapping of the 1974-80 survey estimates of MMB at mating.

In 2010, the NPFMC prescribed that ABCs be established for all BSAI crab stocks at P*=0.49. Under this prescription, annual ACL=ABC levels are established such that the risk of ovefishing, P[ABC>OFL], equals 49%. We derived the relationship between the probability of overfishing and the OFL multiplier (M) via simulation and found the value of M corresponding to P*=0.49 at the specified levels of total scientific uncertainty, σ_{total}=0.13 and σ_{total}=0.33.

P[ABC > OFL] = 0.49	
σ_{TOTAL}	Multiplier (M)
0.13	M_1=1.0
0.33	M_2=0.82

Results

Given the retained catch component (C_{RET}) of the total catch OFL from Eq. 13, if M_1 is the OFL multiplier under σ_{total}=0.13 and M_2 is the multiplier under σ_{total}=0.33, the respective retained catch components at these levels of total scientific uncertainty ($C_{RET,0.13}$ and $C_{RET,0.33}$) are given by:

$$C_{RET,0.13} = C_{RET}\, M_1 \tag{18}$$

$$C_{RET,0.33} = C_{RET}\, M_2 \tag{19}$$

The revised guideline harvest levels for the areas east and west of 166° W longitude under σ_{total}=0.13 ($GHL_{E,0.13}$, $GHL_{W,0.13}$) are estimated as the product of $C_{RET,0.13}$ and the proportion of MMB estimated in the respective areas ($P_{MMB\text{-}E}$, $P_{MMB\text{-}W}$) at the time of the survey. The revised guideline harvest levels for the areas east and west of 166° W longitude under σ_{total}=0.33 ($GHL_{E,0.33}$, $GHL_{W,0.33}$) are estimated as the product of $C_{RET,0.33}$ and the proportion of MMB estimated in the respective areas ($P_{MMB\text{-}E}$, $P_{MMB\text{-}W}$) at the time of the survey.

$$GHL_{E,0.13} = C_{RET,0.13}\, P_{MMB\text{-}E} \tag{20}$$

$$GHL_{W,0.13} = C_{RET,0.13}\, P_{MMB\text{-}W} \tag{21}$$

$$GHL_{E,0.33} = C_{RET,0.33}\, P_{MMB\text{-}E} \tag{22}$$

$$GHL_{W,0.33} = C_{RET,0.33}\, P_{MMB\text{-}W} \tag{23}$$

H. Data Gaps and Research Priorities

A length-based stock assessment model (TCSAM) for this stock is being developed. The TCSAM will incorporate population and survey performance metrics from time series survey data from 1974-2010. The goal is to promote the Tanner crab stock to a Tier-3 management status and to formulate OFLs based on the TCSAM. Antecedent analysis are being preformed to derive model inputs, parameters and schedules. For both males and females, these include the estimation of growth, maturity, survey selectivity, and fishing power. Also required is the reformulation of length-weight relationships, molting probability schedules and growth transition matrices.

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Table 1. Age (months), mean size (mm cw) and instar number for male Tanner crab in Kodiak and the eastern Bering Sea.

	Kodiak		EBS
Instar Number	Mean Size (mm cw)	Mean Age (months)	Mean Size (mm cw)
1	3.4	1.8	-
2	4.5	4.5	-
3	6.0	3.5	-
4	7.9	4.9	-
5	10.4	6.6	-
6	13.7	8.9	-
7	18.1	11.9	17.2
8	23.9	15.9	24.4
9	31.6	21.1	33.5
10	41.7	28.1	45.9
11	53.6	37.3	60.7
12	67.8	47.2	79.3
13	84.6	59.0	98.5
14	106.3	73.1	112.5
15	129.5	85.3	126.8
16	154.3	106.2	141.8
17	180.8	124.5	157.2

Table 2. Eastern Bering Sea *C. bairdi* retained catch in the United States pot, the Japanese tangle net and pot, and the Russian tangle net fisheries, 1965/66-2010/11.

Eastern Bering Sea *Chionoecetes bairdi* Retained Catch (1000T)				
	US Pot	Japan	Russia	Total
Year				
1965/66		1.17	0.75	1.92
1966/67		1.69	0.75	2.44
1967/68		9.75	3.84	13.60
1968/69	0.46	13.59	3.96	18.00
1969/70	0.46	19.95	7.08	27.49
1970/71	0.08	18.93	6.49	25.49
1971/72	0.05	15.90	4.77	20.71
1972/73	0.10	16.80		16.90
1973/74	2.29	10.74		13.03
1974/75	3.30	12.06		15.24
1975/76	10.12	7.54		17.65
1976/77	23.36	6.66		30.02
1977/78	30.21	5.32		35.52
1978/79	19.28	1.81		21.09
1979/80	16.60	2.40		19.01
1980/81	13.47			13.43
1981/82	4.99			4.99
1982/83	2.39			2.39
1983/84	0.55			0.55
1984/85	1.43			1.43
1985/86	0			0
1986/87	0			0
1987/88	1.00			1.00
1988/89	3.15			3.18
1989/90	11.11			11.11
1990/91	18.19			18.19
1991/92	14.42			14.42
1992/93	15.92			15.92
1993/94	7.67			7.67
1994/95	3.54			3.54
1995/96	1.92			1.92
1996/97	0.82			0.82
1997/98	0			0
1998/99	0			0
1999/00	0			0
2000/01	0			0
2001/02	0			0
2002/03	0			0
2003/04	0			0
2004/05	0			0
2005/06	0.43			0.43
2006/07	0.96			0.96
2007/08	0.96			0.96
2008/09	0.88			0.88
2009/10	0.60			0.60
2010/11	0			0

Table 3. Eastern Bering Sea *C. bairdi* total discard and bycatch losses by sex in the directed plus non-directed pot and the groundfish fisheries, 1965/66-2009/10.

Eastern Bering Sea *Chionoecetes bairdi* Discard and Bycatch Losses (1000T)

[HMPot=0.50; HM_{GF}=0.80]

	All Pot		Groundfish		Total	
Year	Male	Female	Male	Female	Male	Female
1965/66	0.78	0.22	2.79	1.85	3.58	2.07
1966/67	1.00	0.28	5.06	3.35	6.06	3.63
1967/68	5.55	1.55	7.88	5.21	13.43	6.77
1968/69	7.35	2.05	5.98	3.96	13.32	6.01
1969/70	11.22	3.14	8.78	5.81	20.00	8.95
1970/71	10.40	2.91	9.76	6.46	20.17	9.37
1971/72	8.45	2.36	10.95	7.25	19.41	9.61
1972/73	6.90	1.93	6.29	4.16	13.19	6.09
1973/74	5.59	1.51	8.60	5.69	14.20	7.21
1974/75	6.62	1.78	11.91	7.88	18.53	9.66
1975/76	8.23	2.11	4.61	3.05	12.84	5.16
1976/77	12.92	3.49	2.00	1.32	14.92	4.81
1977/78	15.42	4.14	1.35	0.89	16.78	5.04
1978/79	10.42	2.58	1.55	1.03	11.98	3.61
1979/80	9.34	2.32	1.24	0.82	10.58	3.14
1980/81	8.29	1.80	1.02	0.67	9.31	2.47
1981/82	2.75	0.64	0.71	0.47	3.46	1.11
1982/83	1.51	0.32	0.22	0.14	1.73	0.47
1983/84	0.54	0.09	0.32	0.21	0.87	0.31
1984/85	1.25	0.23	0.31	0.21	1.57	0.43
1985/86	0.47	0.05	0.19	0.13	0.66	0.17
1986/87	0.61	0.06	0.31	0.21	0.93	0.27
1987/88	2.00	0.27	0.31	0.20	2.30	0.47
1988/89	5.56	0.77	0.22	0.15	5.79	0.92
1989/90	12.04	1.98	0.32	0.21	12.36	2.20
1990/91	22.36	3.50	0.45	0.30	22.82	3.80
1991/92	20.88	3.07	1.22	0.81	22.10	3.88
1992/93	12.36	1.09	1.33	0.88	13.69	1.97
1993/94	6.74	1.23	0.85	0.56	7.59	1.79
1994/95	3.51	1.06	1.01	0.67	4.52	1.73
1995/96	2.42	1.18	0.73	0.49	3.15	1.67
1996/97	0.55	0.16	0.77	0.51	1.32	0.67
1997/98	0.96	0.11	0.57	0.38	1.53	0.49
1998/99	1.05	0.09	0.45	0.30	1.50	0.39
1999/00	0.39	0.07	0.30	0.20	0.69	0.28
2000/01	0.11	0.01	0.36	0.24	0.46	0.25
2001/02	0.18	0.01	0.57	0.38	0.75	0.38
2002/03	0.31	0.02	0.35	0.23	0.66	0.25
2003/04	0.12	0.01	0.20	0.14	0.33	0.15
2004/05	0.06	0.01	0.32	0.22	0.39	0.22
2005/06	0.65	0.04	0.30	0.20	0.95	0.23
2006/07	1.37	0.25	0.35	0.23	1.71	0.48
2007/08	2.01	0.10	0.33	0.22	2.35	0.33
2008/09	0.91	0.03	0.26	0.17	1.17	0.20
2009/10	0.82	0.01	0.15	0.10	0.97	0.11

Table 4. Eastern Bering Sea *C. bairdi* total catch in the directed (retained) and non-directed fisheries, 1965/66-2009/10.

	Eastern Bering Sea *Chionoecetes bairdi* Total Catch (Retained + Non-Retained) (1000T)		
Year	Male	Female	Total
1965/66	5.44	2.03	7.46
1966/67	8.37	3.54	11.91
1967/68	26.82	6.63	33.45
1968/69	31.17	5.91	37.08
1969/70	47.25	8.79	56.04
1970/71	45.41	9.20	54.61
1971/72	39.90	9.47	49.38
1972/73	29.98	6.02	35.99
1973/74	27.22	7.21	34.43
1974/75	33.77	9.66	43.43
1975/76	30.49	5.16	35.65
1976/77	44.93	4.81	49.74
1977/78	52.30	5.04	57.34
1978/79	33.07	3.61	36.68
1979/80	29.59	3.14	32.73
1980/81	22.73	2.47	25.21
1981/82	8.45	1.11	9.56
1982/83	4.12	0.47	4.59
1983/84	1.42	0.31	1.72
1984/85	3.00	0.43	3.43
1985/86	0.66	0.17	0.84
1986/87	0.93	0.27	1.19
1987/88	3.30	0.47	3.77
1988/89	8.97	0.92	9.88
1989/90	23.47	2.20	25.67
1990/91	41.01	3.80	44.81
1991/92	36.53	3.88	40.41
1992/93	29.61	1.97	31.58
1993/94	15.25	1.79	17.04
1994/95	8.06	1.73	9.79
1995/96	5.07	1.67	6.74
1996/97	2.13	0.67	2.81
1997/98	1.53	0.49	2.02
1998/99	1.50	0.39	1.89
1999/00	0.69	0.28	0.96
2000/01	0.46	0.25	0.71
2001/02	0.75	0.38	1.14
2002/03	0.66	0.25	0.90
2003/04	0.33	0.15	0.48
2004/05	0.39	0.22	0.61
2005/06	1.38	0.23	1.61
2006/07	2.67	0.48	3.15
2007/08	3.30	0.33	3.63
2008/09	2.05	0.20	2.25
2009/10	1.58	0.11	1.69

Table 5. Eastern Bering Sea *C. bairdi* male mature biomass and legal male (≥ 138mm cw) biomass at time of the survey, fishery and mating, 1974/75-2010/11.

Eastern Bering Sea *Chionoecetes bairdi* Survey Biomass (1000T)

	Male Mature Biomass			Legal Male Biomass		
Year	Survey	Fishery	Mating	Survey	Fishery	Mating
1974/75	206.29	183.88	143.20	94.52	84.25	65.84
1975/76	257.02	229.10	189.99	168.79	150.46	127.14
1976/77	151.60	135.13	85.12	93.80	83.61	50.45
1977/78	129.63	115.54	58.90	77.66	69.22	31.09
1978/79	79.18	70.58	34.86	41.92	37.37	14.87
1979/80	48.14	42.91	11.71	22.69	20.22	0.46
1980/81	95.65	85.26	59.32	30.96	27.59	13.13
1981/82	55.51	49.48	39.17	10.40	9.27	3.93
1982/83	46.84	41.75	36.06	6.75	6.02	3.40
1983/84	27.22	24.27	21.94	4.40	3.92	3.22
1984/85	23.18	20.67	16.89	6.40	5.71	4.06
1985/86	11.01	9.81	8.78	3.81	3.40	3.27
1986/87	13.74	12.25	10.86	2.50	2.23	2.14
1987/88	26.76	23.85	19.66	5.79	5.16	3.97
1988/89	65.02	57.96	46.81	16.12	14.37	10.65
1989/90	105.65	94.18	67.16	32.41	28.89	16.69
1990/91	103.60	92.34	47.86	45.50	40.55	20.84
1991/92	108.34	96.57	56.41	35.15	31.33	15.73
1992/93	104.33	93.00	59.89	39.59	35.29	18.04
1993/94	58.76	52.38	35.16	18.80	16.76	8.46
1994/95	40.12	35.76	26.36	15.21	13.56	9.51
1995/96	29.62	26.40	20.34	9.47	8.44	6.20
1996/97	24.28	21.64	18.70	8.61	7.68	6.57
1997/98	10.43	9.30	7.42	3.32	2.96	2.85
1998/99	9.99	8.91	7.07	2.02	1.80	1.73
1999/00	12.80	11.41	10.29	2.14	1.91	1.84
2000/01	15.93	14.20	13.20	4.39	3.91	3.77
2001/02	17.79	15.86	14.51	5.90	5.26	5.06
2002/03	17.06	15.21	13.98	6.14	5.47	5.27
2003/04	23.19	20.67	19.56	6.61	5.89	5.67
2004/05	24.73	22.04	20.83	4.83	4.31	4.15
2005/06	42.40	37.80	34.99	10.28	9.16	8.39
2006/07	64.72	57.69	52.84	12.77	11.38	9.99
2007/08	73.56	65.57	59.80	10.48	9.34	8.03
2008/09	61.60	54.91	50.80	14.49	12.91	11.55
2009/10	34.99	31.19	28.44	7.03	6.26	5.43
2010/11	32.08	28.59		8.22	7.33	

Table 6. Eastern Bering Sea *C. bairdi* fishery exploitation rate on male mature biomass (MMB) and legal mature biomass (LMB), 1974/75-2010/11. Exploitation rates are based on biomass; μ on MMB uses total catch losses while μ on LMB uses total retained legal catch.

Eastern Bering Sea *Chionoecetes bairdi*
Exploitation Rate @ Time Fishery

Year	MMB	LMB
1974/75	0.18	0.18
1975/76	0.13	0.12
1976/77	0.33	0.36
1977/78	0.45	0.51
1978/79	0.47	0.56
1979/80	0.69	0.94
1980/81	0.27	0.49
1981/82	0.17	0.54
1982/83	0.10	0.40
1983/84	0.06	0.14
1984/85	0.14	0.25
1985/86	0.07	0.00
1986/87	0.08	0.00
1987/88	0.14	0.19
1988/89	0.15	0.22
1989/90	0.25	0.38
1990/91	0.44	0.45
1991/92	0.38	0.46
1992/93	0.32	0.45
1993/94	0.29	0.46
1994/95	0.23	0.26
1995/96	0.19	0.23
1996/97	0.10	0.11
1997/98	0.16	0
1998/99	0.17	0
1999/00	0.06	0
2000/01	0.03	0
2001/02	0.05	0
2002/03	0.04	0
2003/04	0.02	0
2004/05	0.02	0
2005/06	0.04	0.05
2006/07	0.05	0.08
2007/08	0.05	0.10
2008/09	0.04	0.07
2009/10	0.05	0.10

Table 7. Data used to estimate discard and bycatch losses in the terminal 2010/11 OFL fishery: (a) average Tanner crab fishery performance, (b) Tanner crab discards in the snow and red king crab pot fisheries and snow crab retained catch, and (c) 2007/08-09/10 Tanner crab bycatch in the EBS groundfish fisheries. ***(2010 SAFE - To Be Replaced)***

(a)

Average Observer Fishery Data
EBS Tanner Crab Directed Fishery
[2007/08, 2008/09, 2009/10]

Discard:		1000T	Ratio:
	S.Legal ♂:	0.85	1.05
	Legal ♂:	0.02	0.02
	All ♀:	0.04	0.05
Retained:		0.81	1.0
	Total:	1.72	

(b)

Tanner Crab Non-Directed Pot Fishery Discards
(Combined Opilio + RKC Pot Fisheries)

Year	Opilio Retained	Bairdi Discard	Ratio
	1000T		
2007/08	28.59	1.93	0.07
2008/09	26.56	1.39	0.05
2009/10	21.78	1.57	0.07
2010/11	33.30 *		
		Average:	0.06
		Projected Bairdi Discard (1000T):	2.13

* Projected retained catch OFL for 2009/10 @ 0.75F35%.

(c)

Groundfish Fishery Tanner Crab Bycatch
(Male + Female Combined)

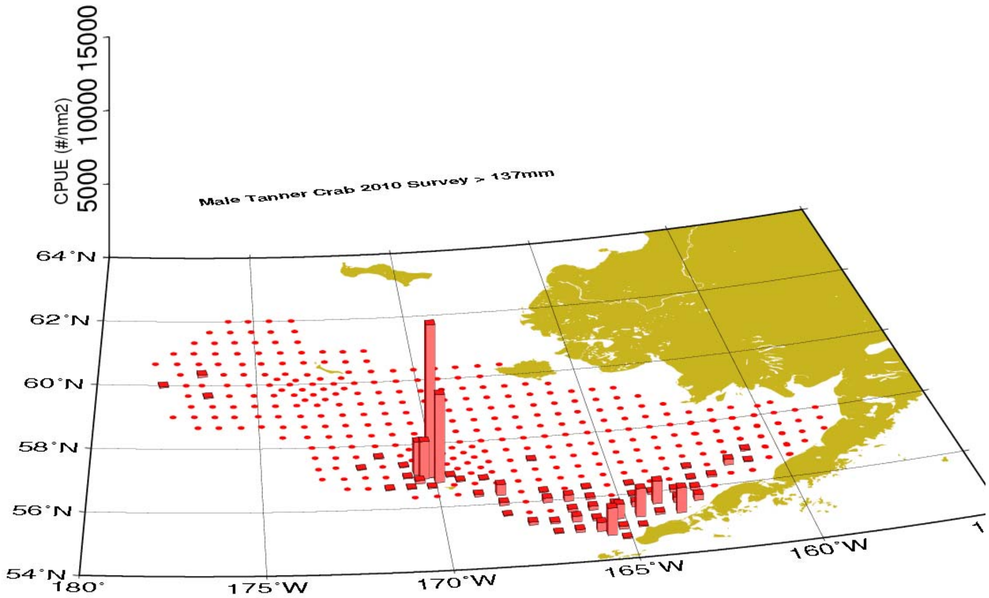
Year		Bycatch (1000T)
2007		0.69
2008		0.53
2009		0.32
	Average:	0.52

Table 8. Catch overfishing limits, stock and fishery metrics for the 2010/11 Eastern Bering Sea *C. bairdi* fishery. (B_{REF}=mean 1969-1980 MMB at the time of mating; μ on MMB is Total Catch OFL/MMB at the time of the fishery). ***(2010 SAFE - To Be Replaced)***

2010/11 Eastern Bering Sea *Chionoecetes bairdi*
Catch OFL, Stock and Fishery Metrics

Metrics (1000T):		
	B_{REF}:	83.80
	MMB @ Mating:	26.07
	B/B_{REF}:	0.31
	F_{OFL}:	0.05
Catch Components (1000T):		
	Total ♂ Catch OFL:	1.45
	Directed Discard Losses MMB:	0.05
	Non-Directed Discard Losses MMB:	1.31
	Retained Part of Total ♂ Catch OFL:	0.09
	Discard + Bycatch Losses ♀:	0.17
	Total ♂ Catch OFL + ♀ Losses:	1.61
Rates:		
	μ on MMB @ Fishery:	0.051

B_{REF}=mean 1969-80 MMB @ mating as proxy for B_{MSY}.



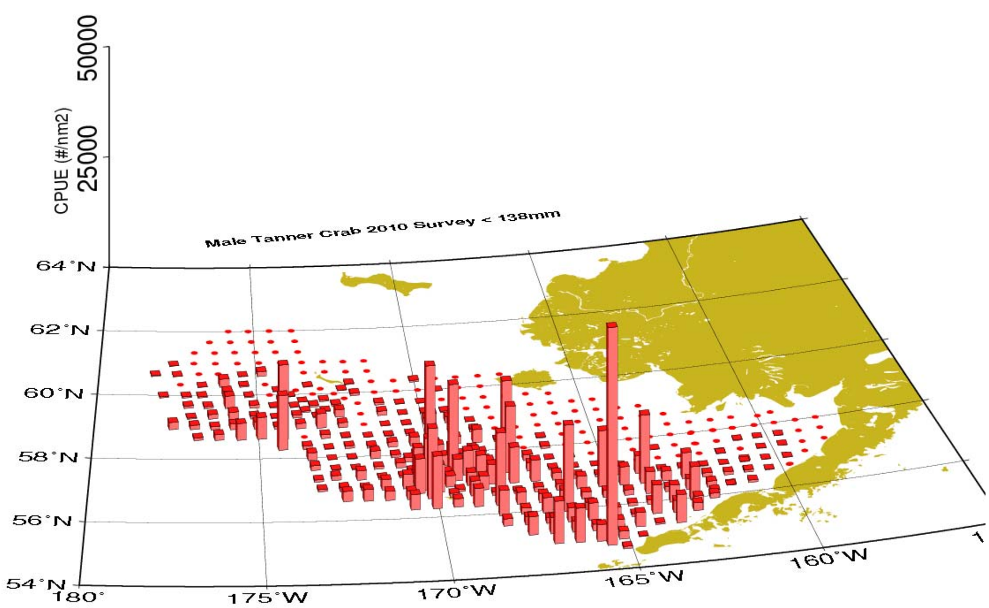


Figure 1. Distribution and abundance of legal (>= 138 mm cw) (top) and sublegal (< 138 mm cw) (bottom) male Tanner crab in the summer 2010 NMFS bottom trawl survey. ***(2010 SAFE - To Be Replaced)***

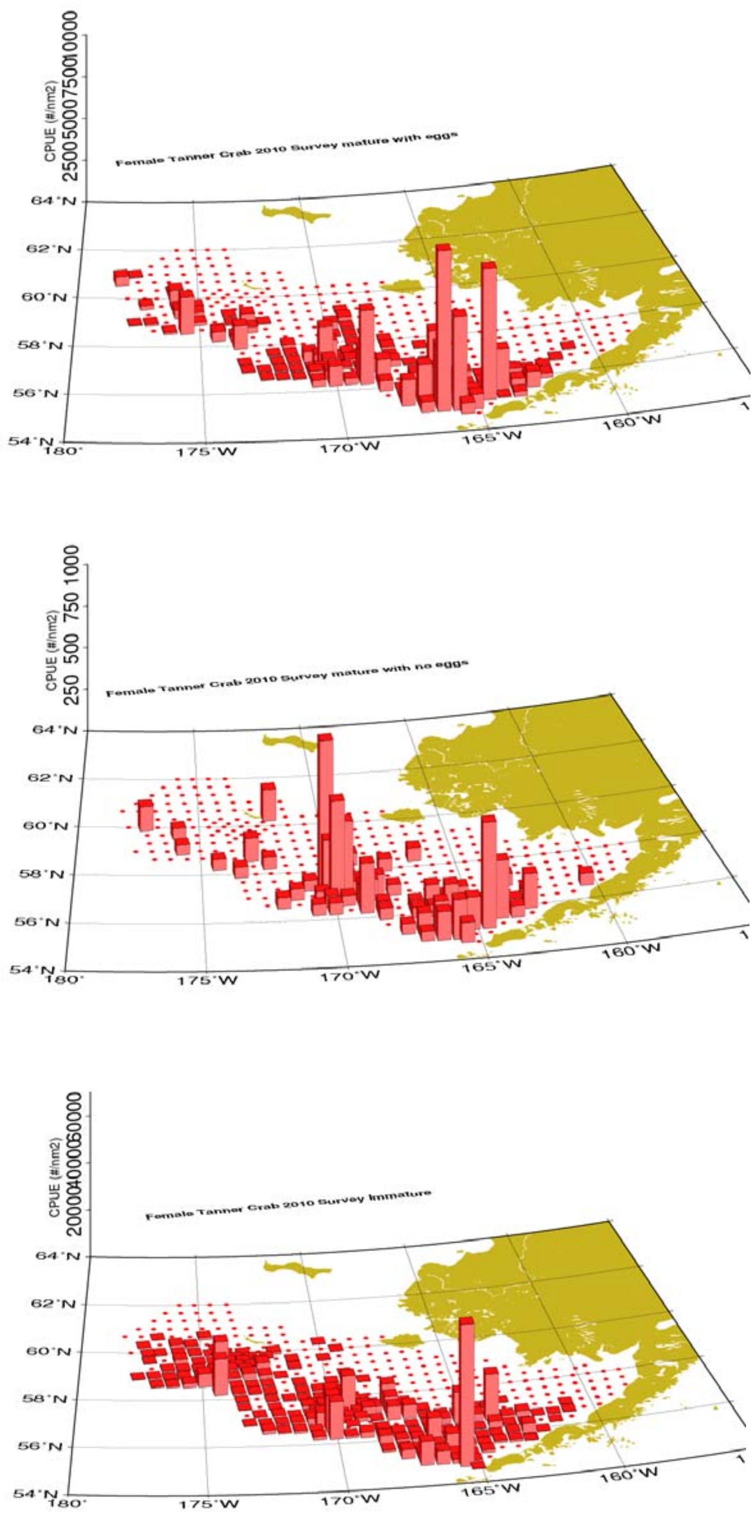


Figure 2. Distribution and abundance of ovigerous (top), barren mature (middle), and immature (bottom) female Tanner crab in the summer 2010 NMFS bottom trawl survey. ***(2010 SAFE - To Be Replaced)***

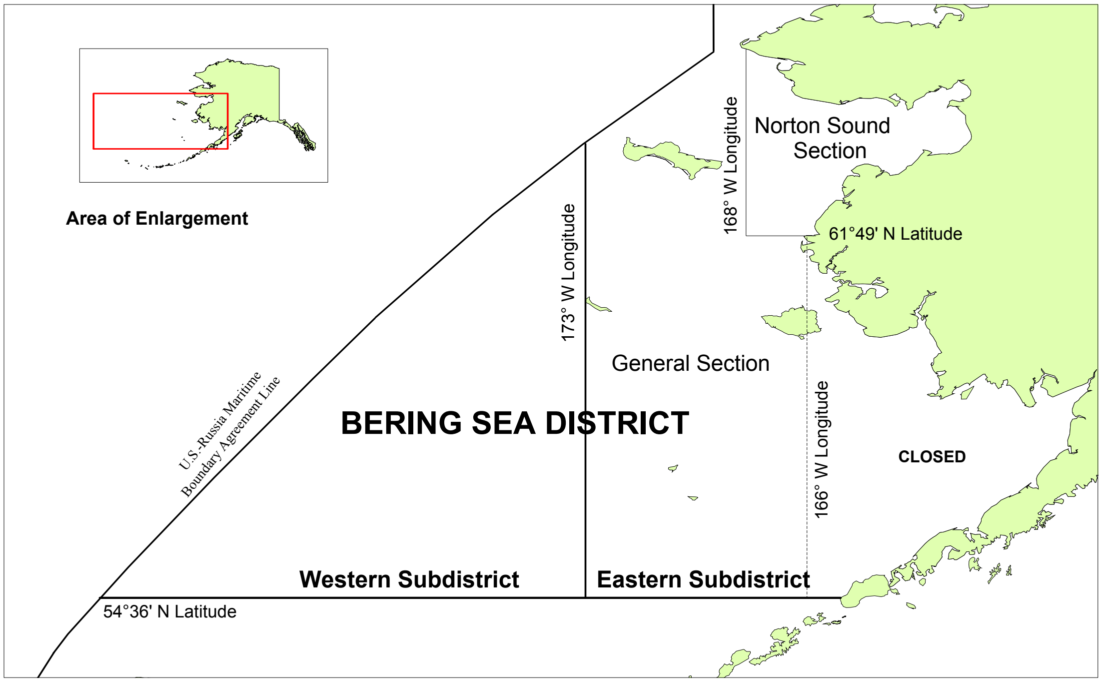
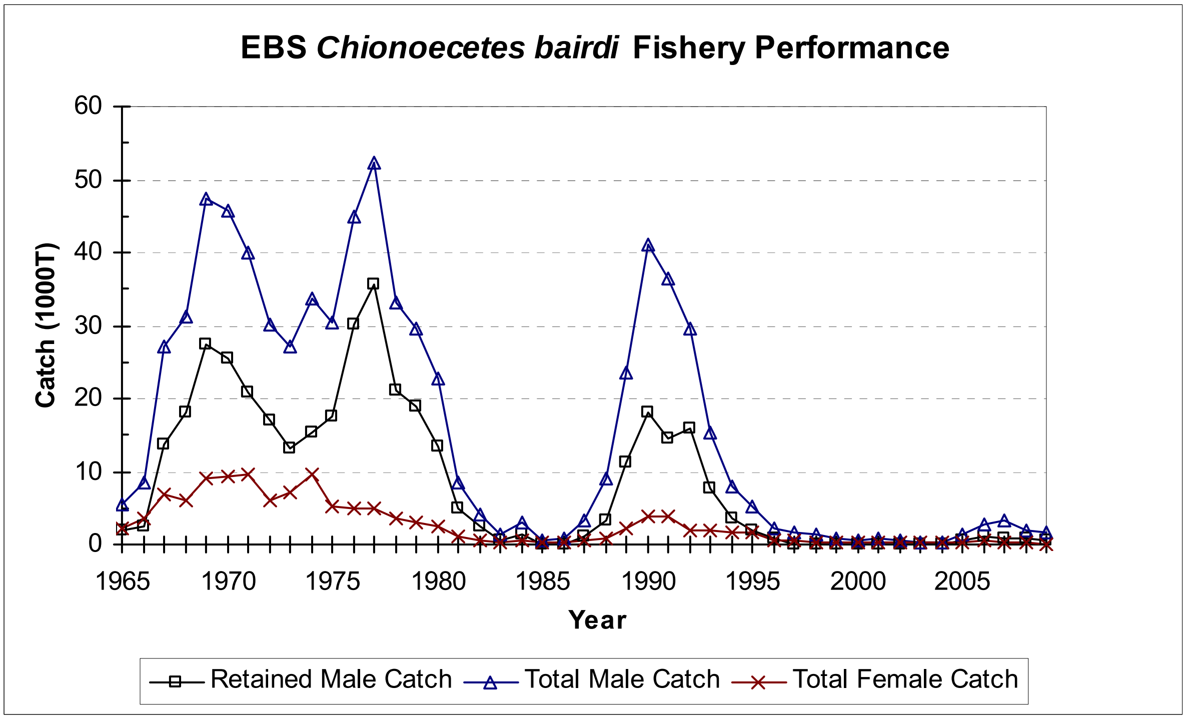


Figure 3. Eastern Bering Sea District of Tanner crab Registration Area J including subdistricts and sections (From Bowers et al. 2008).

(a)



(b)

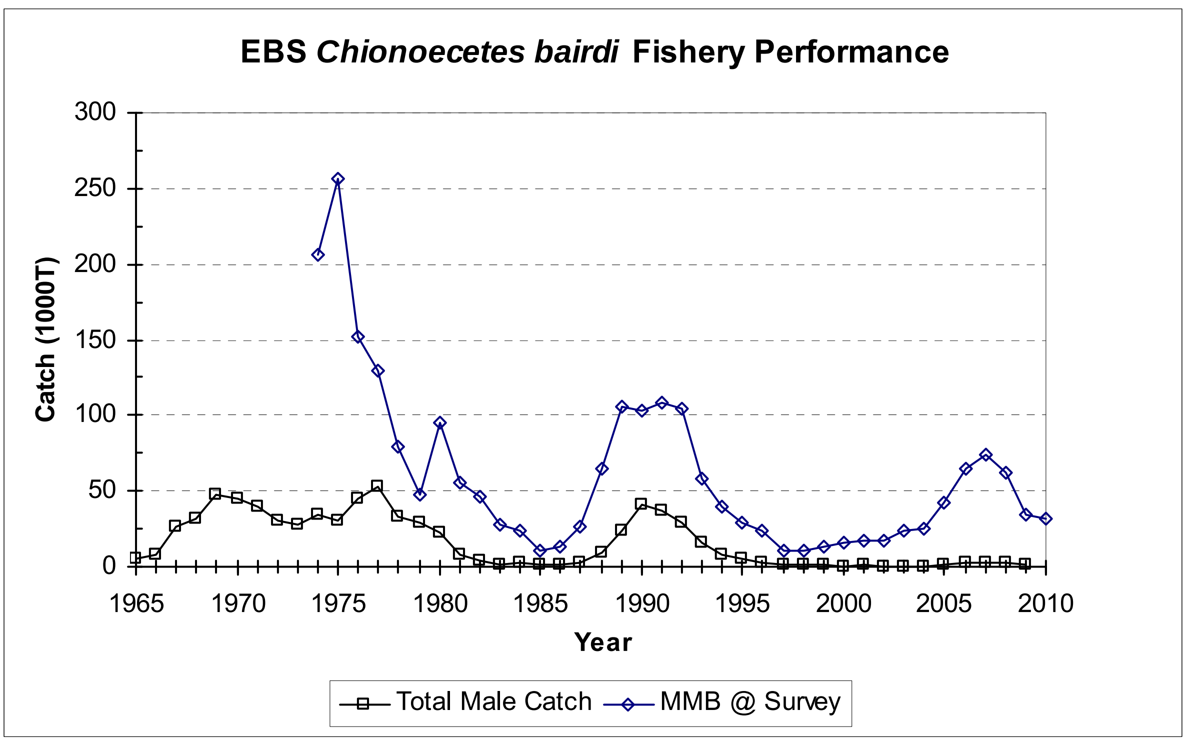


Figure 4. Eastern Bering Sea *C. bairdi* retained male catch, total (retained + bycatch) male catch and total female catch (a), and total male catch v. male mature biomass at the time of the survey (b) for years 1965/66 to 2009/10.

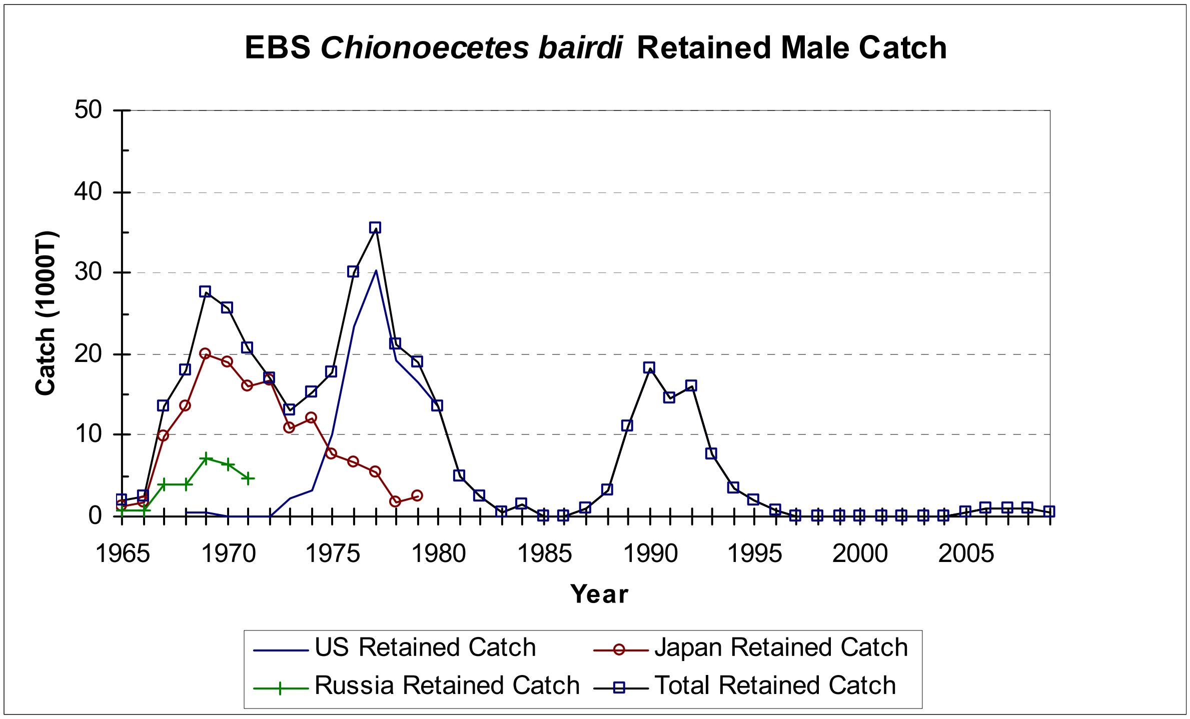


Figure 5. Eastern Bering Sea *Chionoecetes bairdi* retained male catch in the directed United States, Russian and Japanese fisheries, 1965/66 to 2009/10.

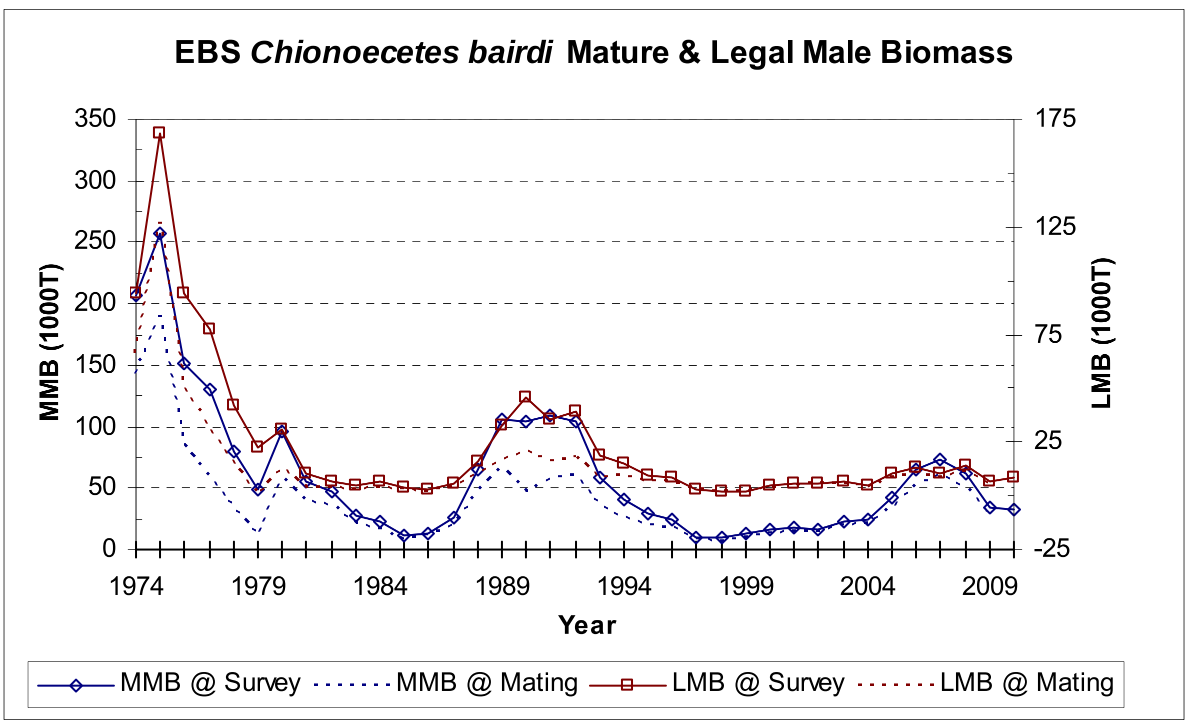
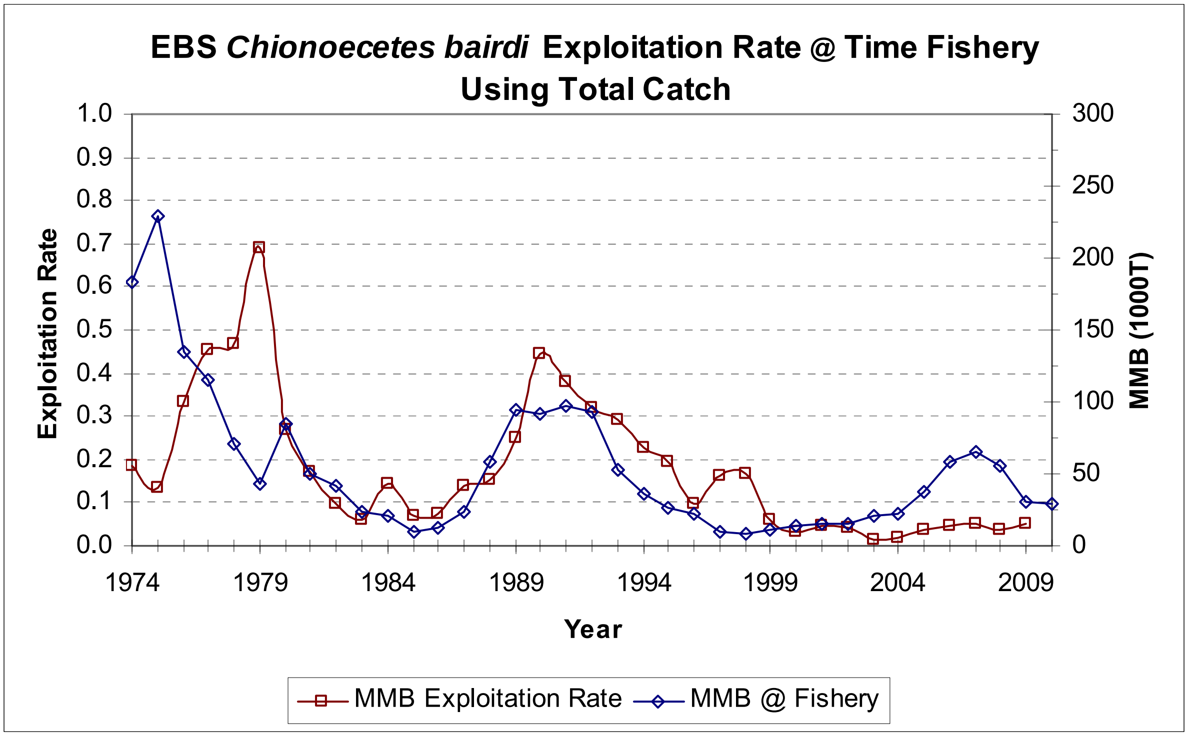


Figure 6. Eastern Bering Sea *C. bairdi* mature and legal male biomass at time of the survey and mating, 1974/75 to 2009/10.

(a)



(b)

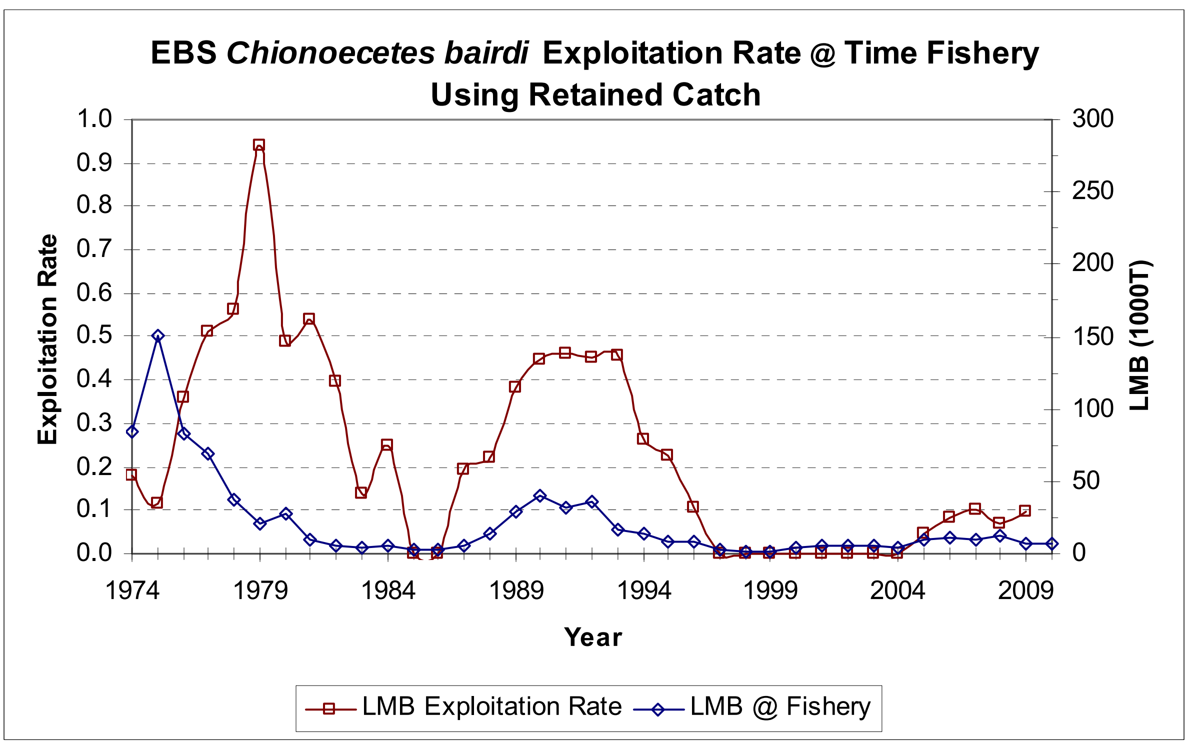


Figure 7. Eastern Bering Sea *C. bairdi* exploitation rate on mature (a) and legal (b) male biomass at the time of the fishery with associated male biomass metric, 1974/75 to 2009/10.

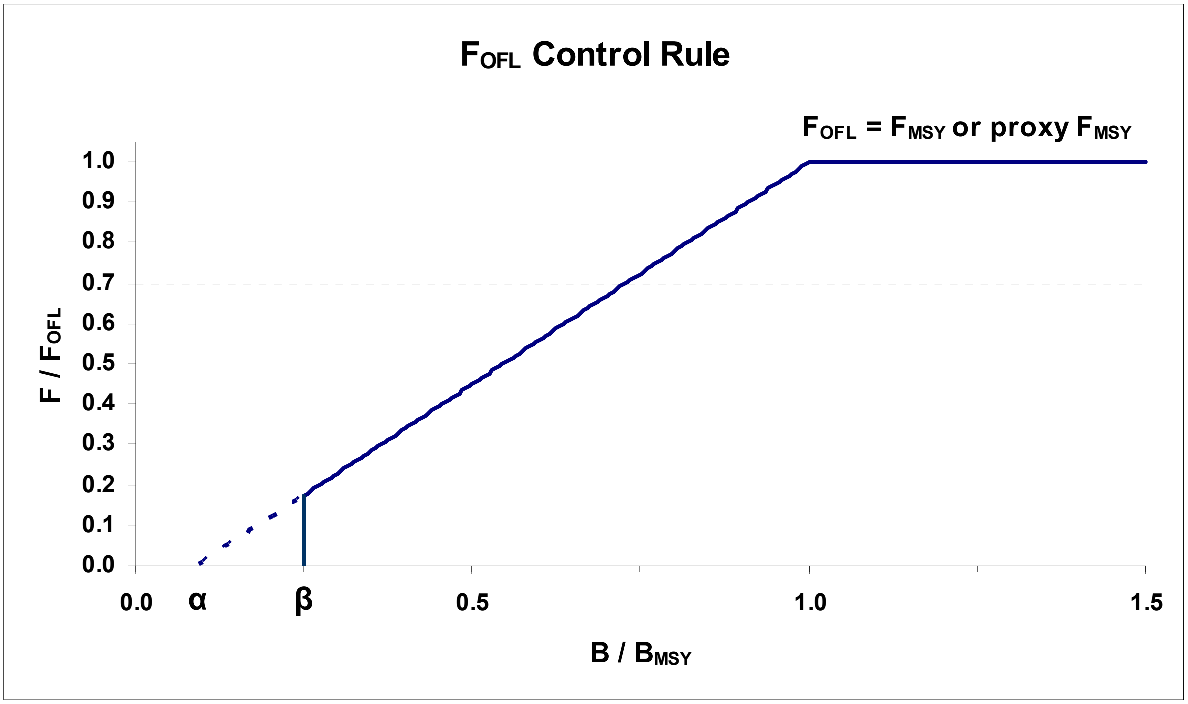


Figure 8. F_{OFL} Control Rule for Tier-4 stocks under Amendment 24 to the BSAI King and Tanner Crabs fishery management plan. Directed fishing mortality is set 0 below β.

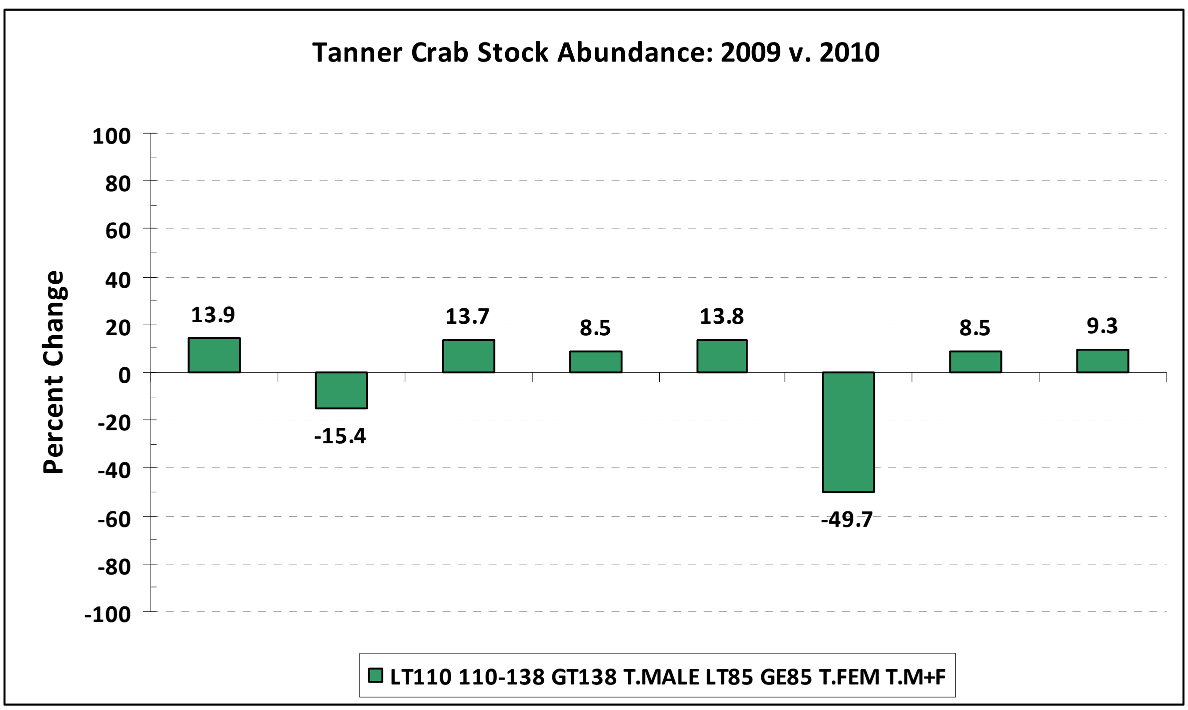
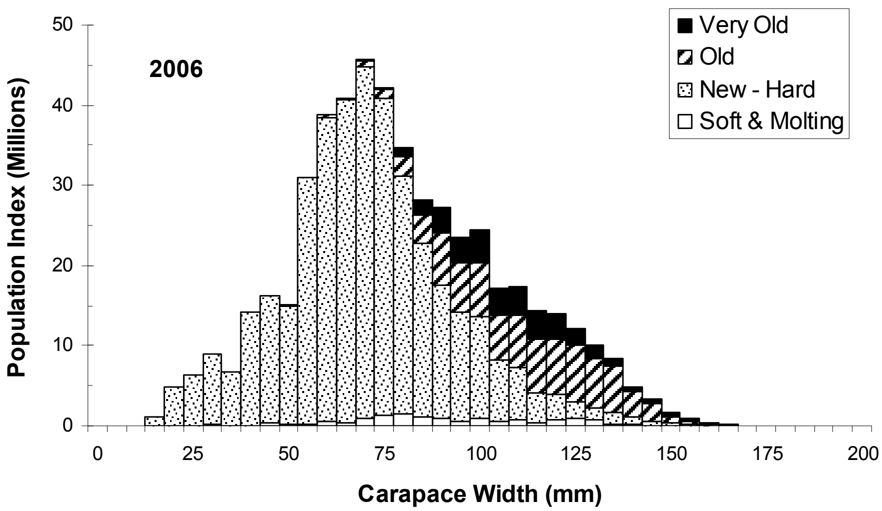


Figure 9. Percent change in Tanner crab stock abundance between 2008/09 and 2009/10 for males (< 110 mm cw, 110-137 mm cw, >= 138 mm cw and total males), females (<85 mm cw, >=85 mm cw and total females), and for total males + females combined. ***(2010 SAFE - To Be Replaced)***

(a)



(b)

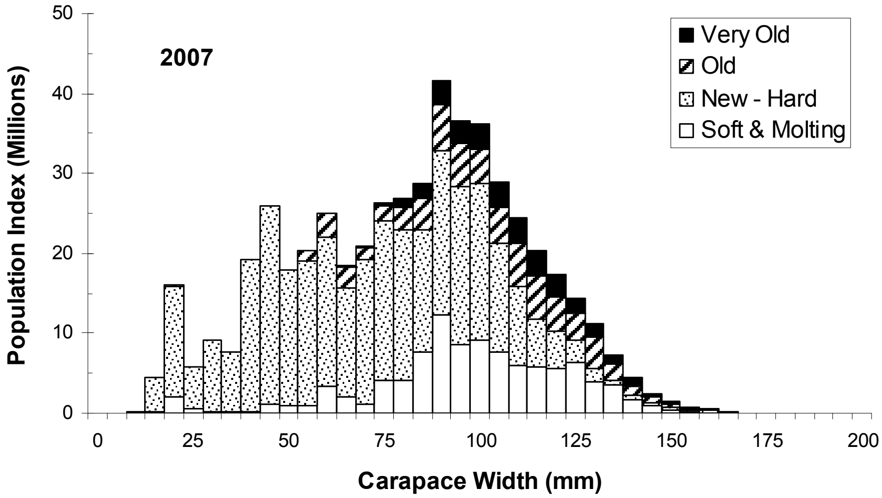
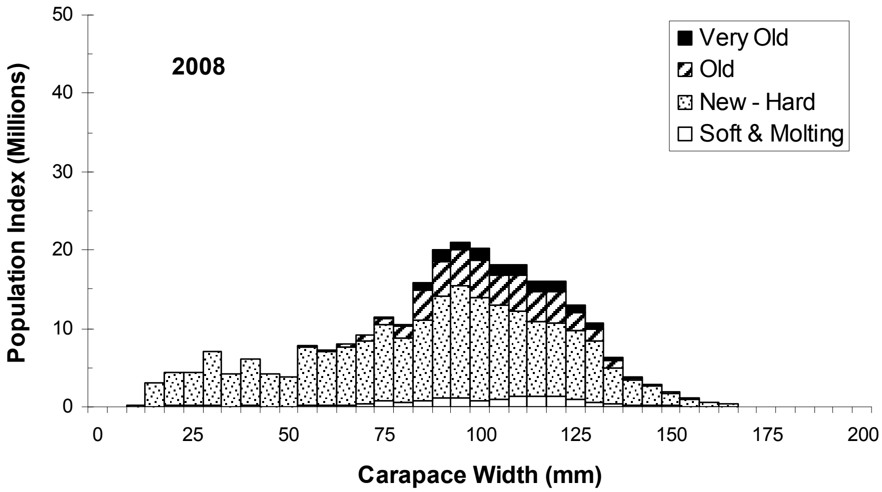


Figure 10 (a-b). Male Tanner crab length frequency by shell class condition sampled by the EBS trawl survey, 2006/07 to 2007/08.

(a)



(b)

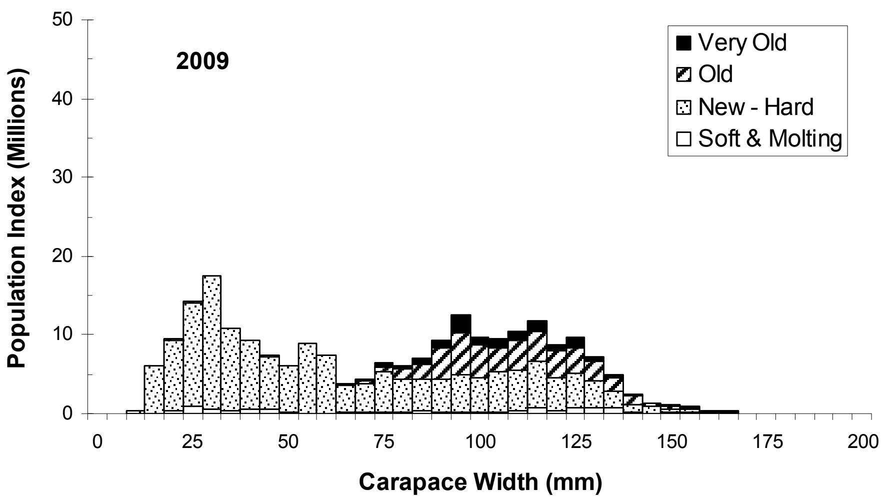


Figure 10 (c-d). Male Tanner crab length frequency by shell class condition sampled by the EBS trawl survey, 2008/09 to 2009/10.

(e)

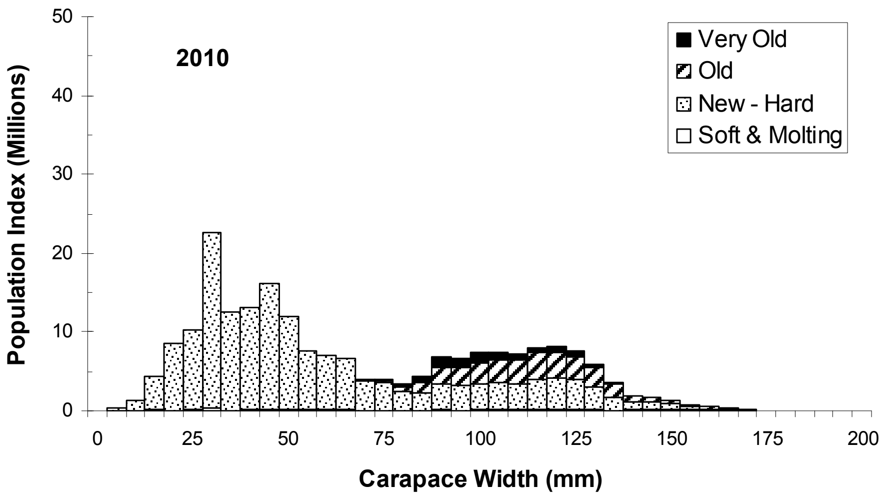
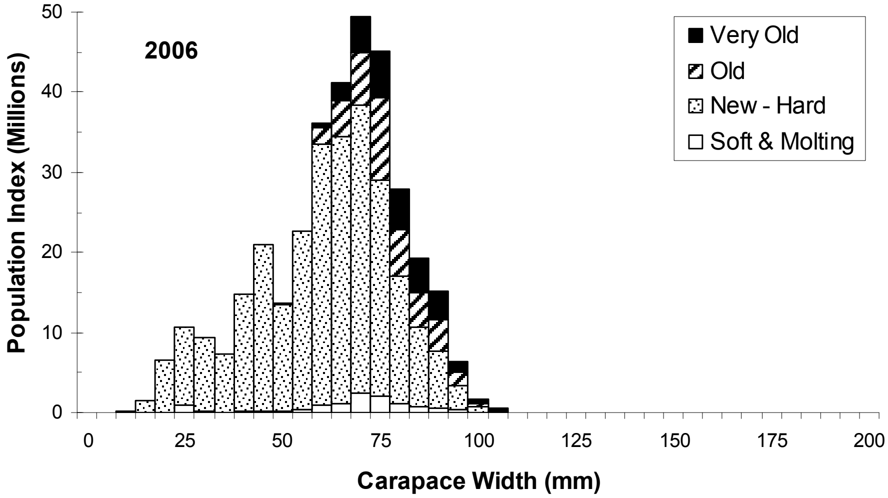


Figure 10 e. Male Tanner crab length frequency by shell class condition sampled by the EBS trawl survey, 2010/11.

(a)



(b)

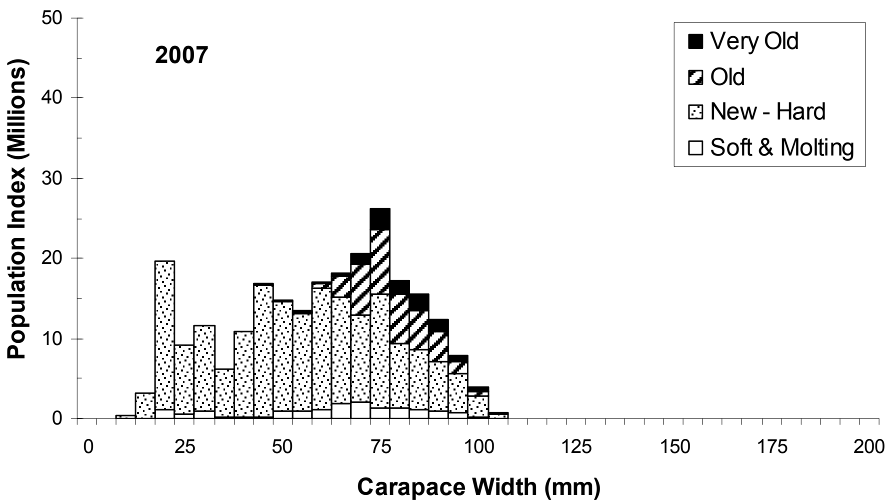
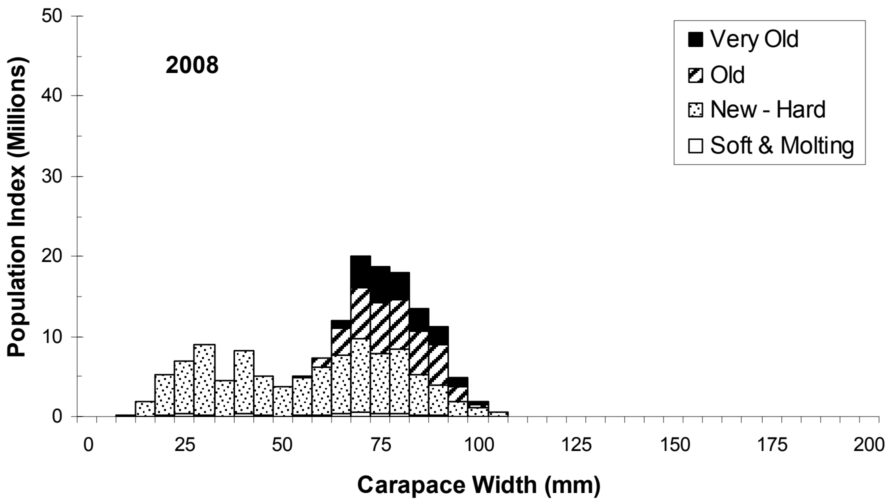


Figure 11 (a-b). Female Tanner crab length frequency by shell class condition sampled by the EBS trawl survey, 2006/07 to 2007/08.

(a)



(b)

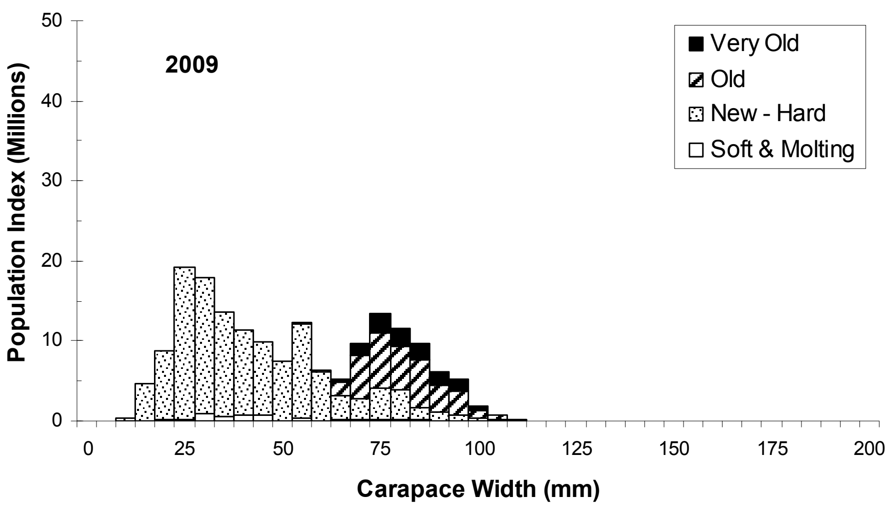


Figure 11 (c-d). Female Tanner crab length frequency by shell class condition sampled by the EBS trawl survey, 2008/09 to 2009/10.

(e)

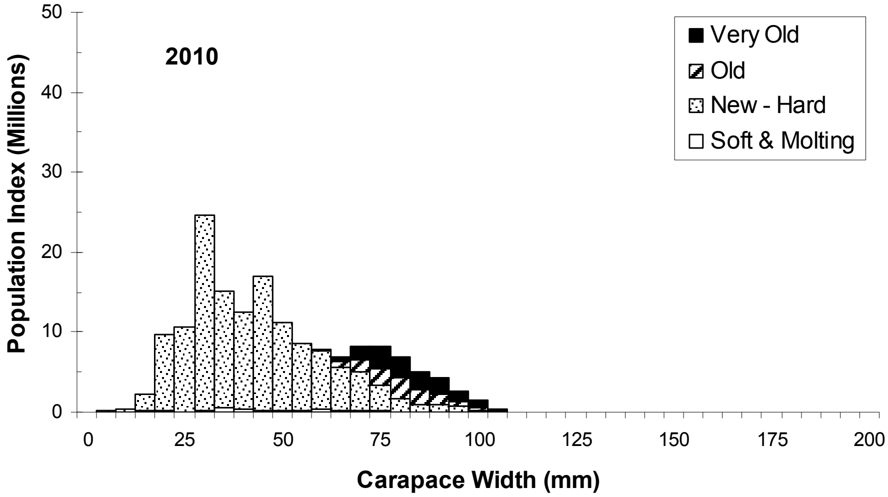


Figure 11 e. Female Tanner crab length frequency by shell class condition sampled by the EBS trawl survey, 2010/11.

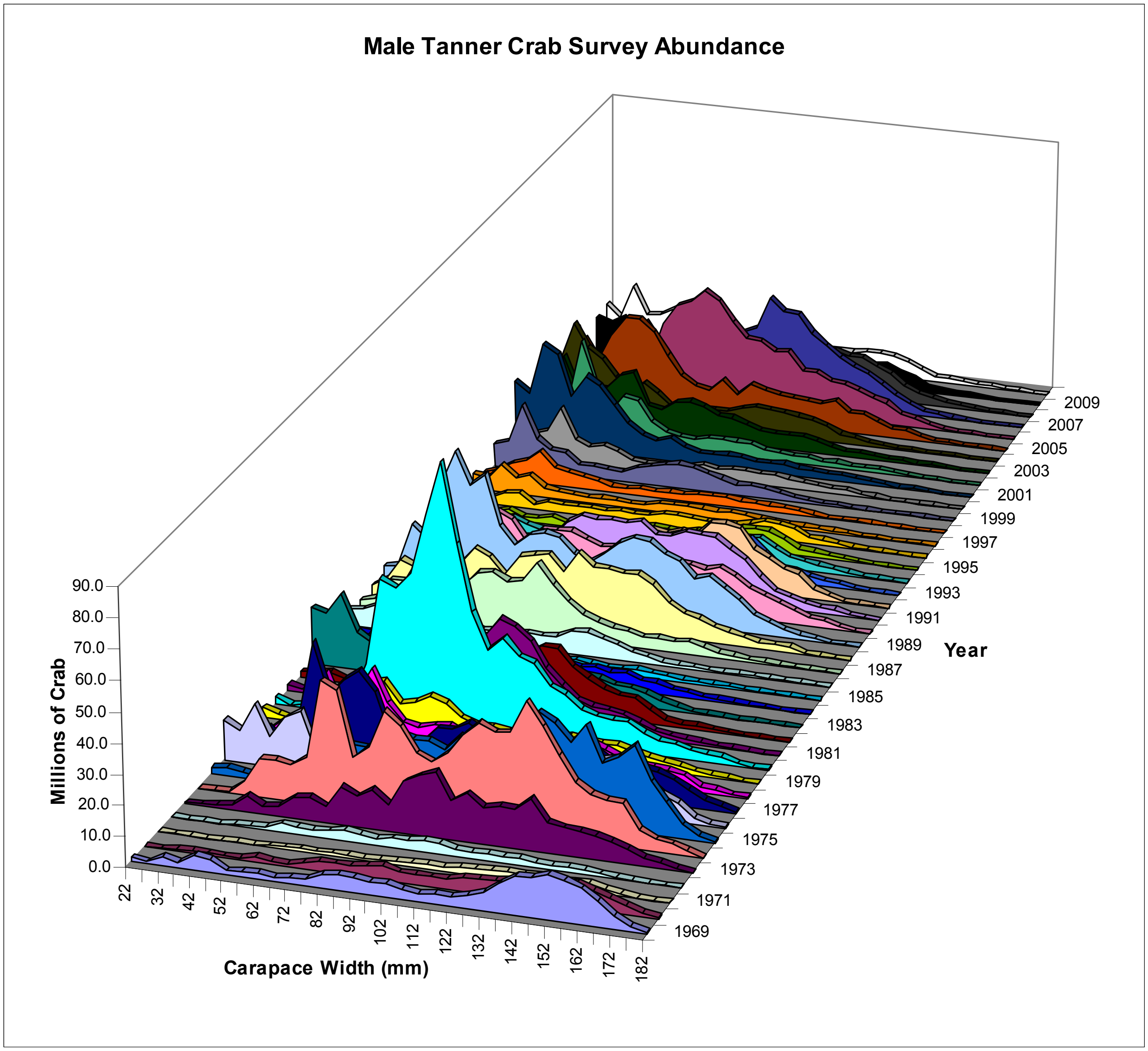


Figure 13. Observed male Tanner crab survey abundance (millions of crab) by carapace width for 1969/70 to 2010/11.

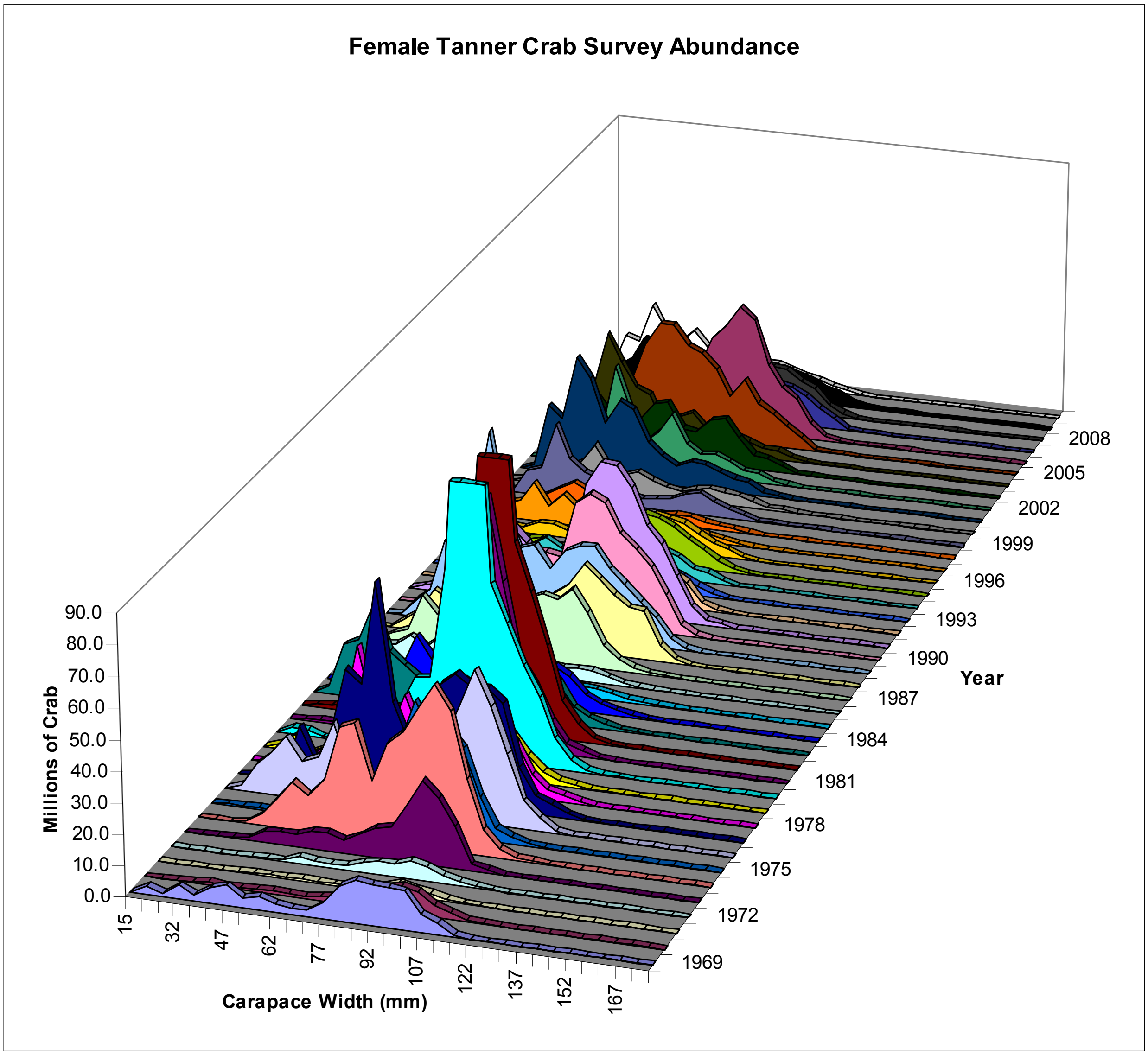


Figure 14 Observed female Tanner crab survey abundance (millions of crab) by carapace width for 1969/70 to 2010/11.

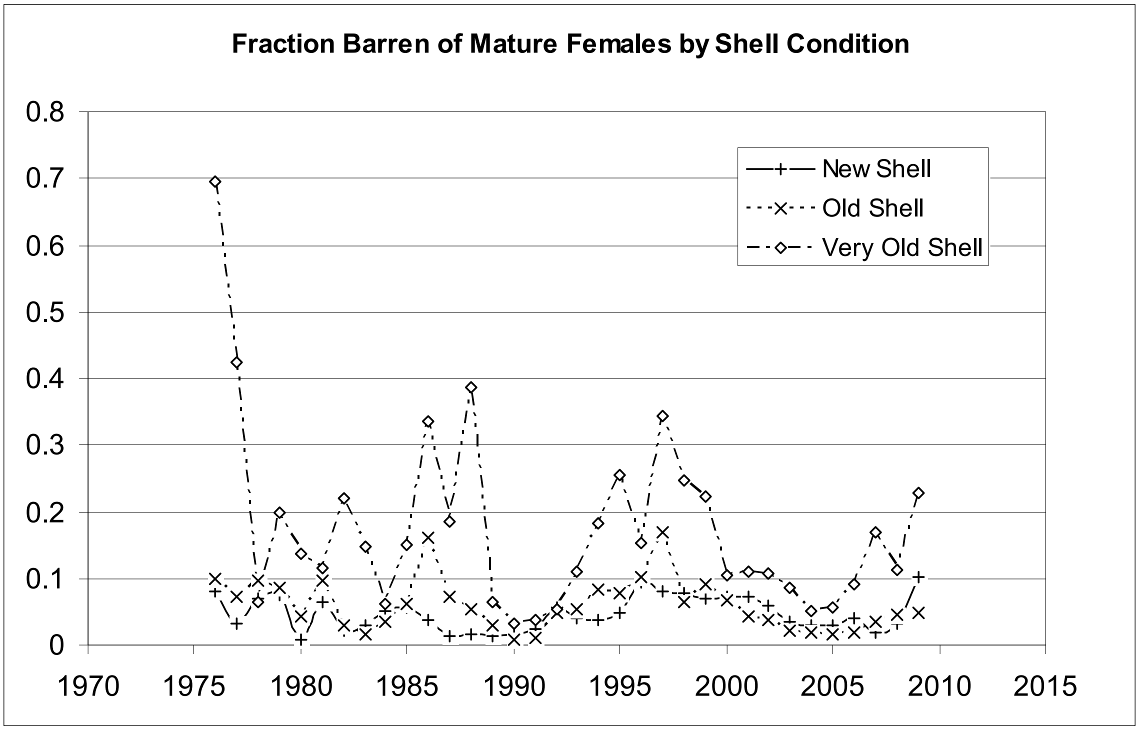


Figure 15. Proportion of female Tanner crab with barren clutches by shell condition from survey data for 1976/77 to 2009/10.

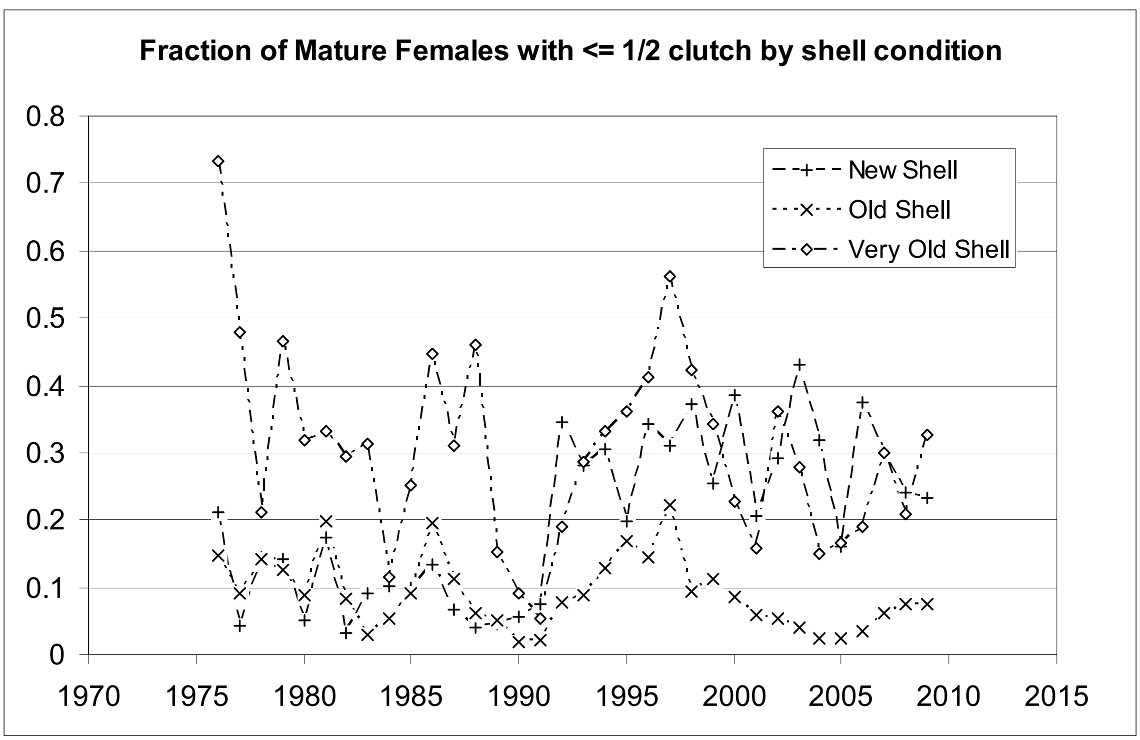


Figure 16. Proportion of female Tanner crab with less than or equal to one-half full clutch by shell condition from survey data 1976/77 to 2009/10.

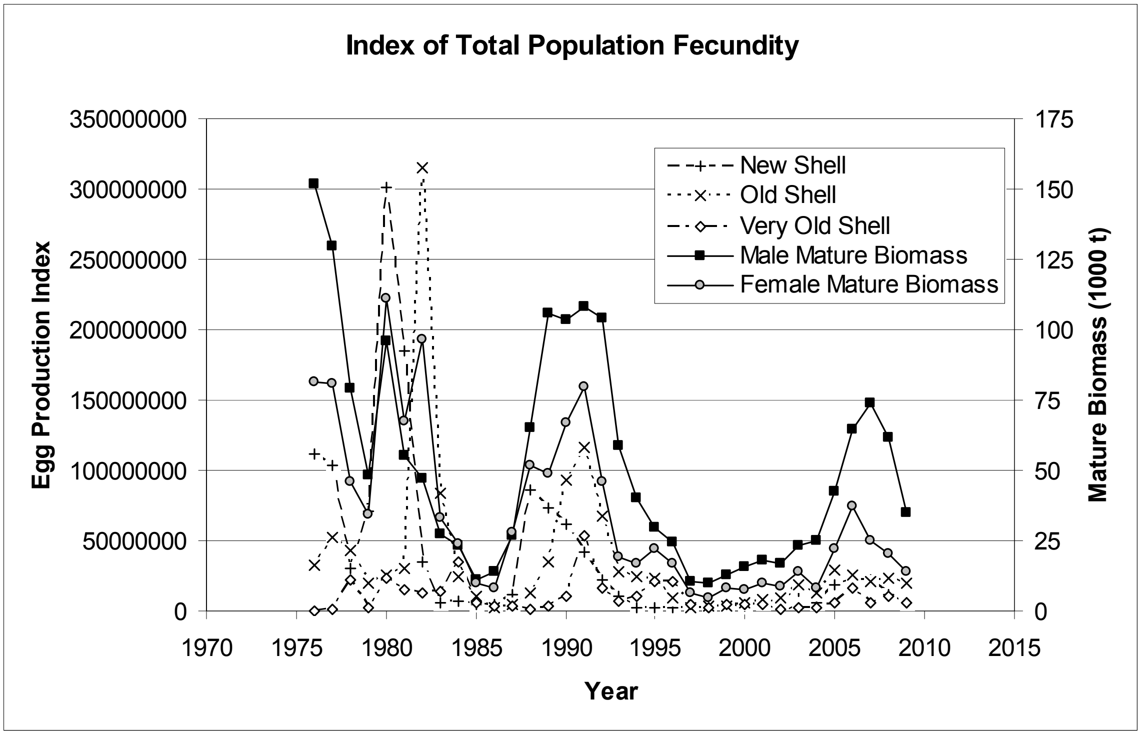


Figure 17. Tanner crab female egg production index (EPI) by shell condition, survey estimate of male mature biomass (1000 t), and survey estimate of female mature biomass (1000 t) from survey data for 1976/77 to 2009/10.

Appendix A. Tanner crab stock assessment model (TCSAM).

Introduction
In this appendix, we report on the current status and performance of the Tanner crab stock assessment model (TCSAM). The TCSAM was presented for review at the Crab Modeling Workshop (Martel and Stram 2011) and to the SSC in March 2011, and will be presented to the CPT in May 2011. Review findings on the model and recommendations for future development from the Workshop and SSC are found in their respective meeting reports.

Summary Overview
In this study, we formulated a length-based assessment model for Tanner crab to characterize the performance of the stock and to serve in estimating overfishing definitions. The model was initiated in 1950 to estimate recruitments to build the stock to fit initial observed survey biomass and length frequency estimates beginning in 1974. We modeled thirty-two 5mm length bins starting from the 25-29 mm bin to a cumulative plus-group bin at 180-184 mm. Fishery-independent estimates of biomass, population metrics and length frequency distributions used in the analysis were from NMFS trawl survey data for 1974-2010. We estimated biological characteristics of male and female crab such as weight-length relationships, maturity schedules and growth functions from extant survey and experimental data, and from the literature to complete model parameterization where necessary. All component fishery-dependent data on Tanner crab were employed. Retained catch data in the domestic and foreign fisheries were available for 1965-2010. Retained male length-frequency by shell condition (1981-2010) and discard length frequency (1992-2010) for male and female crab in the directed fishery were incorporated. Sex-specific length frequencies of discarded crab in the snow crab and Bristol Bay red king pot fisheries (1989-2010), and from groundfish fisheries (1973-2010) were used to characterize non-directed stock losses and fishery performance. Mature male biomass at the nominal time of mating is the population metric used to gauge stock status relative to the limit reference point (B_{MSY} or proxy B_{REF}) and to derive the overfishing limit (F_{OFL}) from the control rule. Male and female survey selectivity was estimated for two time periods (1974-1981 and 1982-2010) to address evolving survey design and gear changes. Survey catchability was fixed at 0.88 for both sexes for the most recent period based on a net selectivity experiment on EBS Tanner crab (Somerton and Otto 1999). Fishery selectivity curves for the directed and all non-directed fleets were estimated for males and females. Post-release mortality for the pot discarded crab was set at 50%, and that for trawl discards set at 80%. Population dynamics in the model are separated by maturity status, shell condition class and sex. Estimated survey mature biomass is fit to observed mature biomass by sex, and survey length frequency is fit to immature and mature crab separately for each sex for the combined shell condition class. Model performance is evaluated by the fit to observed survey and fishery data. $B_{35\%}$ can be derived using model estimates of MMB over the reference period 1974-1980, and as the product of mean recruitment over 1960-1975 spawning biomass per recruit fishing at $F_{35\%}$ for reference. The performance of the Tanner crab stock over the period of record has experienced a one-way trip from high biomass levels early-1970s to exceedingly low levels in the 1980s. The stock was under a rebuilding plan from 1999-2007 and the fishery closed due to stock conservation concerns. The eastern Bering Sea Tanner crab was declared overfished by NOAA Fisheries in 2010. A rebuilding plan must be implemented in 2012 for the 2012/13 fishing season.

The reader is referred to the main document for general and introductory discussion on eastern Bering Sea Tanner crab, stock structure, management unit, fishery history and life-history Here, we present a subset of that discussion pertinent to the assessment model development.

Data Sources
Estimates of Tanner crab stock biomass, population metrics and length frequencies from the trawl survey used in this assessment were those based on area-swept calculations using measured net width spreads for 1974-2010. Survey data for 1974-1975 were recently added to the analysis. Pre-1974 estimates of survey biomass and length frequency distributions were not derived over an area consistent with the standard survey coverage since 1978. Each year for 1969-1973 represented a unique coverage ranging from 25% to 72% of the total Tanner crab distribution sampled since 1978 (Foy, pers. comm.). Stock estimates derived using survey data from these earlier years would underestimate stock biomass and may result in biased low population metrics such as size-sex class distributions of the stock.

Size frequency data on retained Tanner crab from the directed fishery from 1981-1996 and from the 2005/06 to 2009/10 fishing seasons were used in the analysis. Figure A-1 shows the retained male Tanner crab for the domestic and foreign fisheries from 1965 to 2009/10. Observers were placed on directed crab fishery vessels starting in 1990. Size frequency data on the discard catch in the directed fishery were available from 1992-1996 and from 2005-2009/10. Retained catch data were available for the time period modeled (1974-2009/10). Total discard catch was estimated from observer data from 1992 to 2009/10. The discard male catch was estimated from 1969-1991/92 in the model using the estimated fishery selectivities based on observer data from 1992-2009/10 and an applied post-release mortality rate of 50% for pot released crab. Male and female crab length frequency and catch data from the snow crab fishery were available from 1989-2009/10. Male and female Tanner crab length frequency and catch data from the Bristol Bay red king crab fishery were available from 1989-1993 and 1996-2009/10. Trawl bycatch estimates included in the model were from 1973 to 2009/10.

The following table contains the various Tanner crab data components used in the model,

Data Component	**Years**
Retained length frequency by shell condition of male crab in directed fishery	1981-1996, 2005-2009/10
Discarded length frequency of male and female crab in directed fishery	1992/93-1996/97, 2005/06-2009/10
Male and female length frequency and catch in snow crab fishery	1989/90-2009/10
Male and female length frequency and catch in red king crab fishery	1989-1993, 1996-2009/10
Retained catch in directed fishery	1969-2009/10
Trawl bycatch estimates and length frequency	1973-2009/10
Survey length frequency by sex and shell condition	1974-2010
Survey biomass estimates and their coefficients of variation	1974-2010

Life-History

Size at Maturity

We estimated the maturity at length schedules for male and female Tanner crab from extant NMFS trawl survey data. For females, egg and maturity code information collected on the survey from 1976-2009 was analyzed to estimate the maturity curves for new shell females, and for the aggregate class of females all shell conditions combined (Figure A-5). $SM_{50\%}$ for females all shell classes combined was estimated to be 68.8 mm cw, and that for new shell females was 74.6 mm cw. For males, data from the special collection of morphometric measurements taken to the 0.1 mm in 2008 on the NMFS survey served to derive the classification rules between immature and mature crab based on chela allometry using the mixture-of-two-regressions analysis. We estimated classification lines between chela height and carapace width defining morphometric maturity for the unit Tanner crab stock, and for the sub-stock components east and west of 166^{o} W longitude. These rules were then applied to historical survey data from 1990-2007 to apportion male crab to immature and mature population mature at length. We examined and found no significant differences between the classification lines of the sub-stock components (E and W of 166^{o} W longitude), or between the sub-stock components and that of the unit stock classification line. $SM_{50\%,}$ for males all shell condition classes combined was estimated to be 91.9 mm cw, and that for new shell males was 104.4 mm cw (Figure A-6). By comparison, Zheng (1999) in development of the current SOA harvest strategy used knife-edge maturity at >79 mm cw for females and >112 mm cw for males. The maturity curve for new shell females can be considered to represent the conditional probability of new shell immature females maturing given a representative sample of the length composition in the stock by shell condition class and no error in shell classification. For the base model run presented here, the probability of maturing by size for males and females was estimated in the model with the constraint to be a smooth function (Figure A-7). For comparison, the probability of new shell immature males maturing used by Zheng in the Amendment 24 analysis of overfishing definitions is shown (Figure A-7) in which $SM_{50\%}$=130.9 mm cw (NPFMC 2007) (Figure A-7). We're allowing the assessment model to estimate a smooth function for male and female crab representing the probability that a new shell immature crab will molt to maturity which is distinguished from the average fraction of new shell mature crabs in the stock.

Mortality

Due to the lack of age information, Somerton (1981a) estimated mortality separately for individual EBS cohorts of juvenile (pre-recruit) and adult Tanner crab. Somerton postulated that because of net selectivity, age five Tanner crab (mean cw=95 mm) were the first cohort to be fully recruited to the gear; he estimated an instantaneous natural mortality rate of 0.35 for this size class using catch curve analysis. Using catch curve analysis with two different data sets, Somerton estimated natural mortality rates of adult male crab from the fished EBS stock to range from 0.20 to 0.28. When using CPUE data from the Japanese fishery, estimates of M ranged from 0.13 to 0.18. Somerton concluded that M estimates of 0.22 to 0.28 estimated from models that used both the survey and fishery data were the most representative. We examined empirical evidence for reliable estimates of oldest observed age for male Tanner crab. Unlike its congener the snow crab, information on longevity of the Tanner crab is lacking. We reasoned that longevity in a virgin population of Tanner crab would be analogous to that of the snow crab (Turnock and Rugolo 2010) given the close analogues in population dynamic and life-history characteristics, where longevity would be at least 20 years. Employing 20 years as a proxy for longevity and assuming that this age represents the upper 98.5th percentile of the distribution of ages in an unexploited population if observable, M is estimated to be 0.23 (Hoenig 1983). If 20 years is assumed to represent the 95% percentile of the distribution of ages in an unexploited stock, M is estimated to be 0.15. We adopted M=0.23 for both male and female Tanner crab in this analysis. This value corresponds with the range estimated by Somerton.

Growth

Growth relationships for male and female Tanner crab were derived using data collected in the Gulf of Alaska near Kodiak (Munk pers. comm., Donaldson et al. 1981). Growth relationships were based on observed growth data for males to approximately 140 mm cw and for females to approximately 115 mm cw (Figure A-8). Somerton (1981a) estimated growth for EBS Tanner crab based on modal size frequency analysis of Tanner crab in survey data assuming no terminal molt at maturity. Consequently, Somerton's approach did not directly measure molt increments and his findings are constrained by not accounting for the fact that the progression of modal lengths between years was biased as a result that crab ceased growing after their maturity molt. We compared our growth per molt (gpm) relationships with those of Stone et al. (2003) for Tanner crab in southeast Alaska in terms of the overall pattern of gpm over the size range of crab. We found that the pattern of gpm for both males and females is characterized by a higher rate of growth to an intermediate size (90-100 mm cw) followed by a decrease in growth rate from that size thereafter (Figure A-8). Such shaped growth curves are corroborated in work of Stone et al. (2003), Somerton (1981), Donaldson et al. (1981) and in the data of Munk. We modeled the relationship between pre-molt and post-molt size for males and females as a two parameter exponential function of the general form Y=aX^b where Y=post-molt and X=pre-molt carapace width. The fitted growth relationship for males is $Y=1.550X^{0.949}$, and that for females is $Y=1.760X^{0.913}$.

Weight at Length

We derived weight at length relationships for male, immature female and mature female Tanner crab based on special collections of length and weight data on the summer trawl survey in 2006, 2007 and 2009 (Figure A-9). The fitted weight (kg)-length (mm cw) relationship for males of shell condition classes 2 (SC2) through class 5 (SC5) inclusive is: $W=0.00016(cw)^{3.136}$. Those for immature (SC2) and mature (SC2-SC4) females are, respectively, $W=0.00064(cw)^{2.794}$ and $W=0.00034(cw)^{2.956}$.

Model Approach

In this analysis, we developed a length-, sex-, maturity- and shell condition-structured model to characterize stock performance and serve the basis of estimating overfishing definitions. The model structure was developed following the methods of Fournier and Archibald's (1982) with many similarities to Methot (1990). The model was implemented using automatic differentiation software developed as a set of libraries under C++ (ADModel Builder). ADModel Builder can estimate a large number of parameters in a non-linear model using automatic differentiation software extended from Greiwank and Corliss (1991) and developed into C++ class libraries. This software provides the derivative calculations needed to find the objective function via a quasi-Newton function minimization routine (e.g., Press et al. 1992). The model implementation language (ADModel Builder) gives simple and rapid access to these routines and provides the ability to estimate the variance-covariance matrix for all parameters of interest.

The model estimates recruitments beginning in 1950 to build the stock to fit initial observed survey data biomass and length frequency estimates beginning in 1974. This results in 20 additional recruitment parameters. There are 32, 5mm length bins in the model starting from 25-29 mm up to a cumulative bin at 180-184 mm.

Recruitment
Recruitment is determined from the estimated mean recruitment, the yearly recruitment deviations and a gamma function that describes the proportion of recruits by length bin,

$$N_{t,1} = pr_l \, e^{R_0^l + \tau_t}$$

where,

R_0^l Mean recruitment
pr_l Proportion of recruits for each length bin
τ_t Recruitment deviations by year.

Recruitment numbers are estimated equal for males and females in the model.

Crab were distributed into 5mm CW length bins based on a pre-molt to post-molt length transition matrix. For immature crab, the number of crabs in length bin *l* in year *t-1* that remain immature in year *t* is given by,

$$N_{t,l}^{s} = (1 - \phi_l^s) \sum_{l=l_1}^{l'} \psi_{l',l}^{s} \, e^{-Z_{l'}^{s}} N_{t-1,l'}^{s}$$

$\psi_{l',l}^{s}$	growth transition matrix by sex, pre-molt and post-molt length bins which defined the fraction of crab of sex *s* and pre-molt length bin *l'*, that moved to length bin *l* after molting,
$N_{t,l}^{s}$	abundance of immature crab in year *t*, sex *s* and length bin *l*,
$N_{t-1,l'}^{s}$	abundance of immature crab in year *t-1*, sex s and length bin *l'*,
$Z_{l'}^{s}$	total instantaneous mortality by sex *s* and length bin *l'*,
ϕ_l^s	fraction of immature crab that became mature for sex *s* and length bin *l*,
l'	pre-molt length bin,
l	post-molt length bin.

Growth
Growth was modeled using a fixed non-linear exponential function to estimate the mean post-molt carapace width (*Y*) given the mean pre-molt carapace width (*X*) (Figure A-8),

$$Y_{t+1} = aX_t^b$$

Parameters values used in the model and whether parameters were estimated in the model, excluding recruitments and fishing mortality parameters are listed in Table A-5.

Assignment to length bins was made using a two-parameter gamma distribution with mean equal to the growth increment by sex and length, over the 25-185 mm CW range, and a beta parameter which determines the variance,

$$\psi^{s}_{l',l} = \int_{l-2.5}^{l+2.5} gamma(l / \alpha_{s,l'}, \beta_s)$$

where,

$\alpha_{s,l'}$ expected growth interval for sex *s* and size *l'* divided by the shape parameter β,

$\psi^{s}_{l',l}$ growth transition matrix for sex, *s* and length bin *l'* (pre-molt size), and post-molt size *l*.

The Gamma distribution was,

$$gamma(l / \alpha_{s,l}, \beta_s) = \frac{l^{\alpha_{s,l}-1} e^{-\frac{l}{\beta_s}}}{\beta^{\alpha_{s,l}} \Gamma(\alpha_{s,l})}$$

where *l* is the length bin, β was set equal to 0.75 for both males and females as estimated from growth data on EBS Tanner and king crab due to the scant amount of growth data available for snow crab.

Maturity

The probability of an immature crab becoming mature by size was applied to the post-molt size. Crab that matured and underwent their terminal molt in year *t* were mature new shell (SC2) by definition during their first year of maturity. The abundance of newly mature crab ($\Omega^{s}_{t,l}$) in year *t* is given by,

$$\Omega^{s}_{t,l} = \phi^{s}_{l} \sum_{L=l_1}^{l'} \psi^{s}_{l',l} \, e^{-Z^{s}_{l'}} N^{s}_{t-1,l'}$$

Crab that were mature SC2 in year *t-1* no longer molt and move to old shell mature crab (SC3+) in year *t* ($\Lambda^{s}_{t,l}$). Crab that are SC3+ in year *t-1* remained old shell mature for the rest of their lifespan. The total old shell mature abundance ($\Lambda^{s}_{t,l}$) in year *t* is the sum of old shell mature crab in year *t-1* plus previously new shell (SC2) mature crabs in year *t-1*,

$$\Lambda^{s}_{t,l} = e^{-Z^{s,old}_{l}} \Lambda^{s}_{t-1,l} + e^{-Z^{s,new}_{l}} \Omega^{s}_{t-1,l}$$

The fishery is prosecuted in early winter prior to growth in the spring. Crab that molted in year *t-1* remain as SC2 until after the spring molting season. Crab that molted to maturity in year *t-1* are SC2 through the fishery until the spring molting season after which they become old shell mature (SC3).

Male Mature Biomass

Mature male biomass (MMB) was calculated as the sum of all mature males at the time of mating multiplied by respective weight at length.

$$B_t = \sum_{L=1}^{lbins} (\Lambda_{tm,l}^{males} + \Omega_{tm,l}^{males}) W_l^{males}$$

tm	nominal time of mating after the fishery and before molting,
$lbins$	number of length bins in the model,
$\Lambda_{tm,l}^{males}$	abundance of mature old shell males at time of mating in length bin l,
$\Omega_{tm,l}^{males}$	abundance of mature new shell males at the time of mating in length bin l,
W_1	mean weight of a male crab in length bin l.

Catch

Catch of male Tanner crab was taken as a pulse fishery on February 15 (0.62 y) after the beginning of the assessment year (July 1),

$$\hat{C}_t = \sum_l (1 - e^{-(F_{red} * Sel_l^{red} + F_{snow} * Sel_l^{snow} + F_{\tan ner} * Sel_l^{\tan ner} + F_{\mathrm{trawl}} Sel_l^{trawl})}) w_l N_{t,l}^{males} e^{-M0.62}$$

F_{tanner}	full selection fishing mortality (y^{-1}) determined from the control rule using biomass including assessment error,
F_{trawl}	fishing mortality (y^{-1}) for trawl bycatch fixed at 0.01 (average F),
F_{red}	fishing mortality (y^{-1}) for red king crab fishery trawl bycatch,
$Sel_l^{\tan ner}$	directed fishery selectivity for shell condition and length bin l for male crab,
Sel_l^{red}	red king bycatch fishery selectivity for shell condition and length bin l for male crab,
Sel_l^{snow}	snow bycatch fishery selectivity for shell condition and length bin l for male crab,
Sel_l^{trawl}	trawl bycatch fishery selectivity for shell condition and length bin l for male crab,
w_1	mean weight of male crab in length bin l,
$N_{t,l}^{males}$	numbers by length for shell condition class and length bin l,
M	instantaneous natural mortality rate.

Selectivity

The selectivity curves for the total catch (Figure A-10), the retention curve, catch in the red king crab fishery (Figure A-11), catch in the snow crab fishery (Figure A-12), and catch in the groundfish fisheries (Figure A-13), were estimated as two-parameter ascending logistic curves,

$$Sel_l = \frac{1}{1 + e^{(-a(l-b))}}$$

Where *a* is slope and *b* is length at 50% selectivity. Separate selectivity curves for males and females were estimated for the directed, snow and red king crab fisheries.

The probability of retaining crabs by size in the directed fishery with combined shell condition was estimated as an ascending logistic function. The selectivities for the retained catch were estimated by multiplying a two parameter logistic retention curve (same logistic equation as the total selectivity) by the selectivities for the total catch,

$$S_{ret,l} = (selectivity\ total)\left(retention\right)$$

The selectivities for the survey were estimated with three-parameter, ascending logistic functions (Survey selectivities in Figure A-14).

$$Sel_l = \frac{Q}{1+e^{\left\{\frac{-\ln(19)(l-l_{50\%})}{(l_{95\%}-l_{50\%})}\right\}}}$$

Survey selectivities were estimated for two periods, 1974 to 1981 and 1982 to 2010 to address evolving survey design and gear changes. Prior to 1982, the survey employed a different trawl gear and sample design than that implemented in 1982. The spatial coverage of the survey was standardized in 1978 with the exception of the addition of some stations in the northwestern survey area, well outside the distribution of EBS Tanner crab. Years 1974-1981 were considered to have similar coverage of the Tanner crab distribution. During the evolution of the trawl survey, years prior to 1974 had unique coverage temporally and spatially relative to Tanner crab and not included in the analysis as recommended by the Crab Modeling Workshop (Martel and Stram 2011). The maximum selectivity (Q) was fixed at 0.88 for males and females in the most recent period based on results of an underbag selectivity experiment on EBS Tanner crab (Somerton and Otto 1999) (Figure A-14). In that experiment, a secondary net bag underneath the standard trawl was rigged to catch crab that escaped under the standard trawl footrope, and was assumed to have selectivity of 1.0 for all sizes. Q was estimated in the model in the early two periods for both males and females.

Likelihood Equations

Weighting values (λ) for each likelihood equation are shown in Table A-6.

Catch biomass for the directed fishery, snow crab fishery, red king crab fishery and groundfish fishery is assumed to have a normal distribution,

$$\lambda \sum_{t=1}^{T}\left[(C_{t,\,fishery})-(\hat{C}_{t,\,fishery})\right]^2$$

There are separate likelihood components for the retained catch, discard in the directed fishery, discard in the snow crab fishery, discard in the red king crab fishery and groundfish bycatch.

The robust multinomial likelihood is used for length frequencies from the survey and the catch (retained and total) for the fraction of animals by sex in each 5mm length interval. The number of samples measured in each year is used to weight the likelihood. However, since thousands of crab are measured each year, the sample size was set at 200.

$$Length\,Likelihood = -\sum_{t=1}^{T}\sum_{l=1}^{L} nsamp_t * p_{t,l}\log(\hat{p}_{t,l}+o) - Offset$$

$$Offset = \sum_{t=1}^{T}\sum_{l=1}^{L} nsamp_t * p_{t,l}\log(p_{t,l})$$

Where, T is the number of years, $p_{t,l}$ is the proportion in length bin *l*, an *o* is fixed at 0.001.

The survey biomass assumes a lognormal distribution with the inverse of the standard deviation of the log(biomass) in each year used as a weight,

$$\lambda \sum_{t=1}^{ts}\left[\frac{\log(SB_t)-\log(\hat{SB}_t)}{sqrt(2)*s.d.(\log(SB_t))}\right]^2$$

$$s.d.(\log(SB_t)) = sqrt(\log((cv(SB_t))^2+1))$$

Recruitment deviations likelihood equation is,

$$\lambda \sum_{s=1}^{2}\sum_{t=1}^{T}\tau_{s,t}^2$$

Fishery CPUE in average number of crab per pot lift (currently not fit in the model),

$$\sum_{t=1}^{tf}\left[\frac{\log(CPUE_t)-\log(\hat{CPUE}_t)}{sqrt(2)*s.d.(\log(CPUE_t))}\right]^2$$

Penalties on fishing mortality deviations,

$$\lambda \sum_{t=1}^{T}\varepsilon_t^2$$

A total of 231 parameters for the 42 years of data (1974-2010) were estimated in the model (Table A-8). The 93 fishing mortality parameters (one for the directed fishery deviations, 1970-2010, and one mean value), one set for the snow crab fishery, 1992-2010, one set for the red king crab fishery, 1992-2010, and one set for the trawl fishery bycatch, 1973-2010) estimated in the model were constrained so that the estimated catch fit the observed catch closely. There were 61 recruitment deviation parameters estimated in the model, one for the mean recruitment (male and female recruitment were fixed to be equal). There were 16 fishery selectivity parameters. Male and female survey selectivity was estimated for two different periods resulting in 7 parameters estimated (Q and $l_{95\%}$ parameters fixed in most recent period for male and female). A total of 64 parameters were estimated for the probability of maturing smooth constrained functions.

Molting probabilities for mature males and females were fixed at 0, i.e., growth ceases at maturity which is consistent with the terminal molt paradigm (Otto 1998, Tamone et al. 2005). Molting probabilities were fixed at 1.0 for immature females and males. The a and b parameters of the exponential model of post-molt size relative to pre-molt size describing growth of male and female Tanner crab estimated from growth measurements for GOA Tanner crab and fixed in the model (Table A-4). A gamma distribution was used in the growth transition matrix with the beta parameters fixed at 0.75 for males and females. We modeled the variance of the distribution of post-molt size given pre-molt size bin using growth data on male and female GOA Tanner crab and found that a beta of 0.75 resulted in good approximation of the distribution of post-molt sizes over all size bins.

The model separates male and female crab into mature, immature, new shell and old shell for the population dynamics. The model estimate of survey mature biomass is fit to the observed survey mature biomass time series by sex. The model fits the size frequencies of the survey by immature and mature separately for each sex and shell condition combined. The model fits the size frequencies for the pot fishery catch by sex.

Crabs 25 mm cw and larger were included in the model, divided into 32 size bins of 5 mm each, from 25-29 mm to a plus group at 180-184 mm. In this report the term size as well as length will be considered synonymous with cw. Recruits were distributed in the first few size bins using a two parameter gamma distribution with the parameters estimated in the model. The alpha parameter of the distribution was fixed at 11.5 and the beta parameter fixed at 4.0. No spawner-recruit relationship was used in the population dynamics part of the model; annual recruitments were estimated in the model to fit the data.

The NMFS trawl survey occurs in summer each year, generally in June-August. In the model, the time of the survey (July) is considered to be the start of the year rather than January. The modern directed Tanner crab pot fishery has occurred generally in the winter months (January to February) over a contracted time period. In contrast, in the early years the fishery occurred over a more protracted period of time. Natural mortality is applied to the population from the time the survey occurs until the fishery occurs, then catch is extracted instantaneously. The fishing mortality was applied as a pulse fishery at the mean time for that year. After the fishery, growth and recruitment take place in spring, with the remainder of losses due to natural mortality through the end of the year.

Discard mortality

Discard mortality was assumed to be 50% for this assessment. The fishery for snow crabs occurs in winter when low temperatures and wind may result in freezing of crabs on deck before they are returned to the sea. Short-term mortality may occur due to exposure, which has been demonstrated in laboratory experiments by Zhou and Kruse (1998) and Shirley (1998), where 100% mortality occurred under temperature and wind conditions that may occur in the fishery. Even if damage did not result in short term mortality, immature crabs that are discarded may experience mortality during molting some time later in their life.

Projection Model Structure

Variability in recruitment, as well as assessment error, was simulated with temporal autocorrelation. Recruitment was generated from a Beverton-Holt stock-recruitment model,

$$R_t = \frac{0.8\, h\, R_0\, B_t}{0.2\ spr_{F=0}\ R_0(1-h) + (h-0.2)B_t}\ e^{\varepsilon_t - \sigma_R^2/2} \tag{1}$$

$spr_{F=0}$	mature male biomass per recruit fishing at F=0. $B_0 = spr_{F=0}\ R_0$,
B_t	mature male biomass at time t,
h	steepness of the stock-recruitment curve defined as the fraction of R_0 at 20% of B_0,
R_0	recruitment when fishing at F=0,
σ_R	standard deviation for recruitment deviations, estimated at 0.86 from the assessment model.

The temporal autocorrelation error (ε_t) was estimated as,

$$\varepsilon_t = \rho_R \varepsilon_{t-1} + \sqrt{1+\rho_R^2}\ \ \eta_t \qquad where\ \eta_t \sim N(0;\sigma_R^2) \tag{2}$$

ρ_R	temporal autocorrelation coefficient for recruitment, set at 0.6.

Recruitment variability and autocorrelation were estimated using recruitment estimates from the stock assessment model. R_0 and steepness were estimated such that $F_{35\%} = F_{MSY}$ and $B_{35\%} = B_{MSY}$ using a Beverton-Holt stock recruitment relationship.

Assessment error was modeled as a lognormal autocorrelated error on the mature male biomass used to determine the fishing mortality rate in the harvest control rule,

$$B_t^{'} = B_t\, e^{\phi_t - \sigma_I^2/2};\ \ \phi_t = \rho_I \phi_{t-1} + \sqrt{1+\rho_I^2}\ \ \varphi_t \qquad where\ \ \varphi_t \sim N(0;\sigma_I^2)$$

$B_t^{'}$	mature male biomass in year t with assessment error input to the harvest control rule,
B_t	mature male biomass in year t,
ρ_I	temporal autocorrelation for assessment error, set at 0.6 (estimated from the recruitment time series),
σ_I	standard deviation of φ, which determines the magnitude of the assessment error, set at the estimate of variance of ending biomass from the assessment model plus additional uncertainty.

Assessment error in mature male biomass resulted in fishing mortality values applied to the population that were either higher or lower than the values without assessment error. The autocorrelation was assumed to be the same value as that estimated for recruitment. Assessment autocorrelation was used to more closely approximate the process of estimating a biomass time series from within a stock assessment model. The variability in biomass of the simulated population resulted from the variability in recruitment and variability in full selection F arising from implementation error on biomass. Uncertainty in initial numbers by length was added using a lognormal distribution with cv of ending biomass from the assessment model. The population dynamics equations were identical to those presented for the assessment model in the model structure section of this assessment.

New Size Limits Strategy and Fishery Selectivity

In March 2011, the Alaska Board of Fisheries approved a new minimum size limit strategy for Tanner crab that will be in effect for the 2011/12 fishery. The previously minimum legal size limit was 5.5" (138 mm cw) throughout the Eastern Subdistrict. The new regulations established different minimum size limits east and west of 166° West longitude. That for the fishery to the east will be 4.8" (122 mm cw), and that to the west will be 4.4" (112 mm cw). The industry may self-impose retention of crab above 5.5" (138 mm cw) and 5" (127 mm cw) east and west of 166° West longitude, respectively.

For future stock status, since we have no observed data on fishery performance under these proposed regulatory changes, we would initially approximate east-west fishery selectivities and the resultant catch splits in the projection model framework. As a first-order approximation, we would take the current fishery selectivity curve based on 138 mm cw size limit and shifted the curve by the difference between 138 mm and the proposed minimum size limit in each area – i.e., by 16 mm east of 166^{o} W longitude and by 26 mm west of 166^{o} W longitude. Alternatively, we could consider the minimum size limits that the industry is purported to self-impose to adjust the current fishery selectivity curve. Both the retained and total fishery selectivity curves would be shifted in this manner. The split in the catch east-west would be approximated by the proportion of the abundance of crab observed in the 2010 survey east and west of 166^{o} W longitude.

Results

Table A-1 provides the fishery history of observed retained catch in the domestic and foreign Tanner crab fisheries from 1965/66 to 2009/10. The total biomass of discard catch of Tanner crab in the domestic pot fisheries and groundfish fisheries for 1973/74 through 2009/10 is shown in Table A-2. Table A-3 presents the observed survey female, male and total spawning biomass, and observed abundance of legal male crab (≥ 138 mm cw) for years 1974-2010. Model estimates of predicted retained and discard catch of Tanner crab by sex in the directed fishery for 19674/75 through 2009/10 is shown in Table A-4. Table A-5 shows the discard catch by sex in the non-directed pot and groundfish fisheries by sex for years 19674/75 through 2009/10. The predicted total (retained plus discard) Tanner crab catch biomass from the directed and all non-directed fisheries combined for years 19674/75 through 2009/10 is presented in Table A-6. The model estimates of population biomass and abundance, male, female and total mature biomass, abundance of legal males, recruitment to the population, male mature biomass at mating and full-selection fishing mortality rates are presented in Table A-7. Table A-8 provides the parameter values and whether the parameters were estimated in the model, excluding recruitments and fishing mortality parameters. Tables A-9 and A-10 show the likelihood values by component for this run of the assessment model and the weighting factors for the likelihood equations, respectively.

Figure A-2 presents observed retained male catch and predicted retained plus discarded catches of male Tanner crab in the directed fishery, and total male catch in all fisheries combined.

Mature male biomass declined sharply from its high in 1974 to the mid-1980s, increased modestly to a secondary mode in 1990, then declined thereafter through the early-2000s (Figure A-3). The model does not fit the increasing biomass trend in survey biomass in 2005-2008 but does fit the estimated 2009-2010 survey biomass. The increasing biomass trend observed in 2005-2008 was driven principally by the occurrence of hot-spot tows in those years which inflated total biomass estimates (Rugolo and Turnock 2008). Exploitation rates on legal and mature male biomass demonstrated two peaks: the first in the late-1970s through early-1980s and the second in the mid-1990s (Figure A-4).

Fishery selectivity for the total and retained directed male catch was estimated in the model (Figure A-16). Survey selectivity was estimated for two time periods: 1974-1981 and 1981-2010 (Figures A-14 and A-15). For the model presented here, catchability was fixed at 0.88 for males and females in the most recent period (1981-2010) and estimated for both sexes in the earlier two periods, while the 50% and 95% parameters of the selectivity function were estimated in all three periods for both males and females. Somerton and Otto (1999) estimated maximum selectivity for male Tanner crab to be 0.88 (Figures A-14 and A-15).

Model fits to mature male and mature female biomass are shown in Figure A-3 and Figure A-17 respectively. Figure A-10 shows the retention curve for male Tanner crab in the directed fishery. Figures A-11 through A-13 show estimated selectivity curves for male and female Tanner crab in the Bristol Bay red king crab fishery, the snow crab fishery and the groundfish fisheries.

Model fits to the survey length frequencies for females and males including observed survey biomass and lognormal 95% confidence intervals are presented in Figures A-18 and A-20 respectively. Residuals of model fit to survey female and male length frequencies are shown in Figures A-19 and A-21, and that for mature male length frequency in Figure A-22. A summary plot of the model fit to the survey length frequencies for males and females over all years is shown in Figure A-23. Observed survey numbers of legal males and model estimates of the population of legal males and of the survey number of legal males are shown in Figure A-24 and Tables A-3 and A-7.

Figure A-25 illustrates estimates of recruitment to the model of crab 25-50 mm cw and average recruitment from 1950-2004 lagged 5 years. The distribution of recruits by carapace width to the model is shown in Figure A-26. Figures A-27 through A-31 present summary of model fits to length frequencies for retained males, total males, females in the directed fishery, discards in the snow crab fishery and discards in the Bristol Bay red king crab fishery. In the configuration of the model presented here, the parameters of the selectivity functions for male and female crab discarded in the Bristol Bay red king crab fishery are fixed and not estimated. Full-selection fishing mortality rates varied from near zero to 3.75 (Figure A-32, Table A-7). Full-selection fishing mortality rates concur with a history of excessive exploitation, averaging 1.74 (1976/77-1982/83) peaking in 1980/81 at 3.74, and averaging 0.75 (1991/92-1994/95) coincident with peak extraction of catch and decline in stock biomass. Figure A-32 shows realized instantaneous fishing morality rate vs. male mature biomass at mating and the $F_{35\%}$ control rule for the period 1974-2009/10 using $F_{35\%}$=0.69 for illustration. The pattern of recruitment to the model vs. male mature biomass is illustrated in Figure A-33. Figure A-35 presents the trajectory of estimated male mature biomass at the time of mating from 1974-2010. From the high biomass in 1974, MMB at mating has demonstrated a one-way trip of sharply declining biomass through 2000 and remaining at low levels thereafter. A modest mode of MMB was observed in the late-1980s to early-1990s, peaking in 1990 (Figure A-3, Table A-4), but this peak represented only approximately 25% of the male mature biomass estimated in 1974-1970. The male size frequencies from 1974-2009 (Figure A-20) reveals a contraction of the length frequency and shift to smaller sizes coincident with the decline; the modest increase in biomass associated with the 1990 mode is seen in the progression of a lengths from 1987 through 1992. Inspection of the metrics of stock and fishery performance of Tanner crab over the history from 1974-2009 are indicative of stock collapse.

State of Alaska Harvest Strategy Prior to 2011/12

The current SOA harvest strategy (Zheng and Kruse 2000) is as follows: Let MFB_t be the estimate of mature female biomass in the Eastern Subdistrict (i.e., the waters of the Bering Sea District east of 173º W longitude) at the time of the survey in year *t* defined as the estimated biomass of females > 79 mm carapace width (cw), MFB_{t-1} be the estimate of mature female biomass in the Eastern Subdistrict at the time of the survey in the previous year (*t-1*), $MMMA_t$ be the molting mature male abundance in each area east and west of 166° W longitude within the Eastern Subdistrict at the time of the survey in year *t* defined as the estimated abundance of all new-shell males > 112-mm cw plus 15% of the estimated abundance of old-shell males > 112-mm cw, $ELMA_t$ be the exploitable legal male abundance in each area east and west of 166° W longitude within the Eastern Subdistrict at the time of the survey in year *t* defined as the estimated abundance of all new-shell legal males ≥ 138 mm cw plus 32% of the estimated abundance of old-shell legal males ≥ 138 mm cw, W_t be the average weight of legal males in the Eastern Subdistrict east or west of 166° W longitude in year *t* estimated by applying a weight-length relationship to the survey size-frequency data for legal (≥ 138 mm cw) males, HG_{COMP} be the total allowable catch computed for each area east and west of 166° W longitude in the Eastern Subdistrict, HG_{CAP} be the capped total allowable catch derived for each area east and west of 166° W longitude in the Eastern Subdistrict. In applying the control rule, [i] a separate *HG* is determined as the minimum of the HG_{COMP} and the HG_{CAP} for each area east and west of 166° W longitude, and [ii] the *HG* of legal males in each area east or west of 166° W longitude in the Eastern Subdistrict is capped at 50% of the exploitable legal male abundance.

The control rule for the HG during year *t* in each area east and west of 166° W longitude in the Eastern Subdistrict is as follows: (mp=million pounds).

1. If $MFB_{t-1} < 21.0$ mp and $MFB_t < 21.0$ mp, then $HG_{COMP}=0$ and $HG_{CAP}=0$.
2. If $MFB_{t-1} < 21.0$ mp and 21.0 mp $\leq MFB_t < 45.0$ mp, then $HG_{COMP}=0.05MMMA_tW_t$ and $HG_{CAP}=0.25ELMA_tW_t$.
3. If $MFB_{t-1} < 21.0$ mp and $MFB_t \geq 45.0$ mp, then $HG_{COMP}=0.1MMMA_tW_t$ and $HG_{CAP}=0.25ELMA_tW_t$.
4. If $MFB_{t-1} \geq 21.0$ mp and $MFB_t < 21.0$ mp, then $HG_{COMP}=0$ and $HG_{CAP}=0$.
5. If $MFB_{t-1} \geq 21.0$ mp and 21.0 mp $\leq MFB_t < 45.0$ mp, then $HG_{COMP}=0.1MMMA_tW_t$ and $HG_{CAP}=0.5ELMA_tW_t$.
6. If $MFB_{t-1} < 21.0$ mp and $MFB_t \geq 45.0$ mp, then $HG_{COMP}=0.2MMMA_tW_t$ and $HG_{CAP}=0.5ELMA_tW_t$.

As previously noted, the SOA has proposed changes to the current harvest strategy for the 2011/12 fishery. If approved by the BOF, the operational framework of these new regulations will be incorporated in future model development and for stock projections.

Overfishing Control Rule

Amendment 24 to the NPFMC fishery management plan (NPFMC 2007) introduced revised the definitions for overfishing for EBS crab stocks. The information provided in this assessment is sufficient to estimate overfishing limits for Tanner crab under Tier 3b. The OFL control rule for Tier 3b is based on spawning biomass-per-recruit reference points (NPFMC 2007).

$$F = \begin{cases} Bycatch\ only,\ Directed\ F = 0, & if\ \dfrac{B_t}{B_{REF}} \leq \beta \\[2ex] \dfrac{F_{REF}\left[\dfrac{B_t}{B_{REF}} - \alpha\right]}{(1-\alpha)} & if\ \beta < \dfrac{B_t}{B_{REF}} < 1 \\[2ex] F_{REF} & if\ B_t \geq B_{REF} \end{cases} \qquad (12)$$

where,

B_t	mature male biomass at time of mating in year t
B_{REF}	proxy for B_{MSY} defined as mature male biomass at time of mating resulting from fishing at F_{REF} (proxy F_{MSY})
F_{REF}	F_{MSY} proxy defined as the fishing mortality that reduces mature male biomass at the time of mating-per-recruit to specified percent of its unfished level
α	fraction of B_{REF} where the harvest control rule intersects the x-axis if extended below β
β	fraction of B_{REF} below which directed fishing mortality is 0

The total catch, including all bycatch of both sexes from all fisheries, is estimated by the following equation,

$$catch = \sum_f \sum_s \sum_l \frac{F_{f,s,l}}{F_{tot,s,l}} (1 - e^{-(F_{tot,s,l})}) w_{s,l} N_{s,l} \, e^{-M*.62}$$

Where, $N_{S,l}$ is the 2010 numbers in length bin l and sex s at the time of the survey estimated from the population dynamics model, M_s is natural mortality by sex, 0.62 is the time elapsed (in years) from when the survey occurs to the fishery, F_{tot} is the value estimated from the OFL control rule using the 2010 mature male biomass projected forward to the time of mating time (February 2011), $F_{f,s,l}$ is partial value for each directed and non-directed fishery component in length bin l by sex, and $w_{s,l}$ is the mean weight in length bin l by sex. Fishery selectivities by length for the total catch (retained plus discard) and retained catch estimated from the population dynamics model (Figure A-16).

B_{MSY} Proxy $B_{35\%}$

Estimation of biological reference points have not been conducted at this stage of model development. The estimation of a $B_{35\%}$ proxy for B_{MSY} depends on model estimates of recruitment and biomass which cannot be meaningfully employed until the model meets review and is adopted for stock assessment. The biomass reference point B_{REF} used in the draft 2011 stock assessment (Rugolo and Turnock 2011) for OFL setting under Tier 4 was estimated using estimates of MMB at the time of mating from observed survey data over the reference period 1974-1980 at 83,300 t. The average model estimate of MMB at mating over this reference period (1974-1980) was 98,703 t. Prior to the adoption of Amendment 24 to the NPFMC fishery management plan (NPFMC 2007) that established new overfishing definitions, the B_{MSY} proxy was 86,000 t, computed as the 15 year average (1983-1997) of observed survey total mature biomass (TMB) of males and females combined. The male mature biomass component of this average TMB was 52,800 t. This period comprises years in which the stock dramatically declined from peak abundance in the late-1960s to early-1970s to exceedingly low levels (Figure A-3 and Table A-3), punctuated by a modest mode of the model estimate of male survey mature biomass in 1990 at 110,930, 45.7% of the 1974 estimate of male survey mature biomass (248,880 t) (Figure A-3, Tables A-3 and A-7).

The Tanner crab stock experienced a one-way trip from high biomass levels in the late-1960s and early-1970s to exceedingly low levels in the 1980's which persist to the present. The performance of stock and fishery metrics reveal that the Tanner crab stock collapsed over the observed period of record. The stock was declared overfished in 2010 by the NOAA Fisheries and in need of a rebuilding plan (Rugolo and Turnock 2010). The historical bimodal distribution in male mature biomass (Figure A-3) reflects that of the attendant directed fisheries with peak modes in the early- and late-1970s and early-1990s, and depressed stock status subsequent to these modes (Figures A-1 and A-2). Full-selection fishing mortality rates estimated in the model concur with a history of excessive exploitation (Figure A-32, Table A-7), averaging 1.74 (1976/77-1982/83) peaking in 1980/81 at 3.74, and averaging 0.75 (1991/92-1994/95) coincident with peak extraction of catch (Figure A-3) and decline in stock biomass. If the $F_{35\%}$ OFL control rule established by Amendment 24 had been in effect from 1974/75-2009/10, in 15 of the 40 years the realized F would have exceeded the limit and overfishing determined to have occurred (Figure A-34). Fishing mortality rates on male Tanner crab have often exceeded the OFL, however, this did not constitute overfishing in the past because Amendment 24 was only implemented in 2008.

Recruitment to the model of crab 25 mm to 50 mm cw fluctuated widely from 1950-2005 displaying a prominent period of moderately high recruitment in the mid-1950s to mid-1960s (Figure A-25). These recruitments gave rise to the peak male mature biomass levels in the early-1970s. Irrespective of any limitations in the model to suitably characterize recruitment to the stock, observed male mature biomass and/or the stock recruitment relationship, recruitments to the stock following the precipitous decline in stock biomass from the 1970s have been low and insufficient to maintain the stock at levels observed pre-1980 or provide for meaningful stock growth.

The EBS Tanner crab stock was under a rebuilding plan for 1999-2009 and the directed fishery closed from 1997 to 2004 as a result of severely depressed stock status. Under the former BSAI King and Tanner Crab fishery management plan (NPFMC 1998) and overfishing definitions, the Tanner crab stock was above the B_{MSY} level indicative of a restored stock for the second consecutive year in 2007 and declared rebuilt. As previously noted, the increasing biomass trend observed in 2005-2008 was driven principally by the occurrence of hot-spot tows in those years which inflated total biomass estimates (Rugolo and Turnock 1998). As such, it was doubtful that male mature biomass increased in the manner suggested by estimates of observed survey biomass. Mature male biomass declined sharply in 2008-2010 from the apparent 2007 level and declared overfished in 2010 (Rugolo and Turnock 2010) and deemed by the NOAA Fisheries in need of a rebuilding plan.

$B_{35\%}$ under Tier 3 is defined as the product of average recruitment over a specified time period and the spawning biomass per recruit fishing at $F_{35\%}$. For the history of fishing relative to the OFL Control Rule (Figure A-34), a $B_{35\%}$ is shown at 83.3 thousand t as a reference B_{REF} only from the Tier-4 assessment (Rugolo and Turnock 2011). We will examine alternative estimates of the $B_{35\%}$ proxy for B_{MSY} that include estimates of recruitments that gave rise to stock biomass levels in the early period prior to the collapse, and simulating the stock to estimate B_0 from which $B_{35\%}$ can be derived. The goal is to derive a meaningful estimate of $B_{35\%}$ for use in the Tier-3 specification for this stock.

Table A-1. Eastern Bering Sea Tanner crab retained catch in the United States pot, the Japanese tangle net and pot, and the Russian tangle net fisheries, 1965/66-2010/11.

Eastern Bering Sea *Chionoecetes bairdi* Retained Catch (1000T)				
	US Pot	Japan	Russia	Total
Year				
1965/66		1.17	0.75	1.92
1966/67		1.69	0.75	2.44
1967/68		9.75	3.84	13.60
1968/69	0.46	13.59	3.96	18.00
1969/70	0.46	19.95	7.08	27.49
1970/71	0.08	18.93	6.49	25.49
1971/72	0.05	15.90	4.77	20.71
1972/73	0.10	16.80		16.90
1973/74	2.29	10.74		13.03
1974/75	3.30	12.06		15.24
1975/76	10.12	7.54		17.65
1976/77	23.36	6.66		30.02
1977/78	30.21	5.32		35.52
1978/79	19.28	1.81		21.09
1979/80	16.60	2.40		19.01
1980/81	13.47			13.43
1981/82	4.99			4.99
1982/83	2.39			2.39
1983/84	0.55			0.55
1984/85	1.43			1.43
1985/86	0			0
1986/87	0			0
1987/88	1.00			1.00
1988/89	3.15			3.18
1989/90	11.11			11.11
1990/91	18.19			18.19
1991/92	14.42			14.42
1992/93	15.92			15.92
1993/94	7.67			7.67
1994/95	3.54			3.54
1995/96	1.92			1.92
1996/97	0.82			0.82
1997/98	0			0
1998/99	0			0
1999/00	0			0
2000/01	0			0
2001/02	0			0
2002/03	0			0
2003/04	0			0
2004/05	0			0
2005/06	0.43			0.43
2006/07	0.96			0.96
2007/08	0.96			0.96
2008/09	0.88			0.88
2009/10	0.60			0.60
2010/11	0			0

Table A-2. Eastern Bering Sea Tanner crab discards (1000 t) in the domestic pot fisheries and groundfish fisheries, 1973/74-2009/10. No discard mortality applied.

Discards (1000 t) of Tanner Crab by Fishery

	Tanner Crab		Snow Crab		Red King Crab		Groundfish
Year	Male	Female	Male	Female	Male	Female	♀+♂
1973/74							17.872
1974/75							24.735
1975/76							9.575
1976/77							4.150
1977/78							2.808
1978/79							3.225
1979/80							2.576
1980/81							2.114
1981/82							1.474
1982/83							0.449
1983/84							0.671
1984/85							0.644
1985/86							0.399
1986/87							0.649
1987/88							0.640
1988/89							0.463
1989/90							0.671
1990/91							0.943
1991/92							2.545
1992/93	10.986	1.787	25.759	1.787	1.188	0.029	2.758
1993/94	6.831	1.814	14.530	1.814	2.967	0.198	1.760
1994/95	3.130	1.270	7.124	1.271	0.000	0	2.096
1995/96	2.762	1.760	4.797	1.759	0.000	0	1.524
1996/97	0.236	0.091	0.833	0.229	0.027	0.004	1.597
1997/98	0	0	1.750	0.226	0.165	0.003	1.179
1998/99	0	0	1.989	0.175	0.119	0.003	0.934
1999/00	0	0	0.695	0.145	0.076	0.004	0.630
2000/01	0	0	0.146	0.022	0.067	0.002	0.739
2001/02	0	0	0.323	0.011	0.043	0.002	1.184
2002/03	0	0	0.557	0.037	0.062	0.003	0.721
2003/04	0	0	0.193	0.026	0.056	0.003	0.422
2004/05	0	0	0.078	0.014	0.048	0.003	0.676
2005/06	0.286	0.027	0.968	0.043	0.042	0.002	0.621
2006/07	1.243	0.322	1.462	0.169	0.026	0.003	0.717
2007/08	2.100	0.100	1.872	0.102	0.056	0.009	0.694
2008/09	0.431	0.014	1.119	0.050	0.270	0.004	0.531
2009/10	0.071	0.002	1.324	0.014	0.150	0.001	0.204

Table A-3. Observed survey female, male and total spawning biomass (1000 t) and observed abundance of legal male crab ≥ 138mm (million crab), 1974-2010.

Observed Survey Mature Male and Female Biomass and Legal Male Abundance				
Year	Mature Biomass (1000 t)			Male ≥ 138 mm (10^6 crab)
	Male	Female	Total	
1974	206.3	94.9	301.2	87.53
1975	257.0	66.0	323.0	151.45
1976	151.6	81.1	232.7	86.07
1977	129.6	80.8	210.4	68.49
1978	79.2	45.9	125.1	37.65
1979	48.1	34.2	82.3	21.33
1980	95.6	111.3	207.0	28.53
1981	55.5	67.3	122.8	10.14
1982	46.8	96.6	143.5	6.82
1983	27.2	32.9	60.1	4.70
1984	23.2	23.9	47.1	6.19
1985	11.0	9.7	20.7	3.54
1986	13.7	7.8	21.6	2.27
1987	26.8	28.1	54.9	5.73
1988	65.0	51.6	116.7	15.60
1989	105.7	49.0	154.6	32.73
1990	103.6	66.7	170.3	42.93
1991	108.3	79.4	187.8	33.89
1992	104.3	45.7	150.0	39.65
1993	58.8	19.4	78.2	18.22
1994	40.1	17.1	57.2	14.81
1995	29.6	22.4	52.0	9.45
1996	24.3	17.0	41.3	8.56
1997	10.4	6.3	16.7	3.24
1998	10.0	4.7	14.7	1.97
1999	12.8	8.3	21.1	2.07
2000	15.9	7.8	23.7	4.60
2001	17.8	9.7	27.5	5.97
2002	17.1	8.9	26.0	5.94
2003	23.2	14.1	37.3	6.31
2004	24.7	8.1	32.8	4.50
2005	42.4	22.1	64.5	10.41
2006	64.7	37.1	101.8	13.36
2007	73.6	25.2	98.8	10.90
2008	61.6	20.6	82.2	14.39
2009	35.0	14.2	49.2	6.91
2010	32.1	10.3	42.3	8.01

Table A-4. Predicted retained and discard catch (1000 t) by sex in the directed Tanner crab pot fishery, 1974/75-2009/10.

Directed Fishery Predicted Retained and Discard Catch Biomass (1000 t)				
Year	Retained	Discard Catch		Total
	Male Catch	Male	Female	Male Catch
1974/75	15.22	5.77	1.25	20.99
1975/76	17.65	6.35	1.43	24.00
1976/77	30.00	11.97	2.94	41.98
1977/78	35.50	20.87	5.04	56.37
1978/79	21.02	15.11	3.50	36.13
1979/80	18.84	13.78	3.66	32.62
1980/81	13.32	17.57	6.50	30.88
1981/82	5.31	12.77	4.36	18.08
1982/83	2.71	2.94	0.70	5.65
1983/84	0.76	0.38	0.08	1.13
1984/85	1.53	0.51	0.10	2.04
1985/86	0	0	0	0
1986/87	0	0	0	0
1987/88	0.84	0.29	0.09	1.13
1988/89	2.92	1.34	0.37	4.27
1989/90	10.86	5.08	1.16	15.94
1990/91	17.97	7.62	1.73	25.58
1991/92	14.18	5.93	1.43	20.10
1992/93	15.15	6.63	1.76	21.78
1993/94	7.62	3.55	1.02	11.18
1994/95	3.65	1.60	0.45	5.25
1995/96	2.39	0.84	0.23	3.23
1996/97	0.88	0.26	0.08	1.14
1997/98	0	0	0	0
1998/99	0	0	0	0
1999/00	0	0	0	0
2000/01	0	0	0	0
2001/02	0	0	0	0
2002/03	0	0	0	0
2003/04	0	0	0	0
2004/05	0	0	0	0
2005/06	0.51	0.17	0.04	0.68
2006/07	1.16	0.40	0.09	1.56
2007/08	1.33	0.43	0.09	1.77
2008/09	0.84	0.25	0.05	1.09
2009/10	0.53	0.16	0.03	0.69
2010/11				

Table A-4. Predicted discard catch (1000 t) by sex in the non-directed domestic pot and groundfish fisheries by sex, 1974/75-2009/10.

Non-Directed Fishery Predicted Discard Catch Biomass (1000 t)					
Year	Snow Crab Fishery		Red King Crab Fishery		GF Fishery
	Male	Female	Male	Female	Male + Female
1974/75	0.64	0.11	3.36	0.34	19.79
1975/76	0.42	0.08	3.61	0.38	7.67
1976/77	0.63	0.12	3.48	0.41	3.33
1977/78	0.67	0.12	2.61	0.34	2.26
1978/79	0.84	0.16	1.95	0.26	2.60
1979/80	1.94	0.43	1.32	0.20	2.08
1980/81	2.13	0.53	0.75	0.16	1.77
1981/82	1.82	0.40	0.66	0.13	1.30
1982/83	0.84	0.16	0.88	0.12	0.54
1983/84	0.71	0.13	1.14	0.12	0.66
1984/85	0.63	0.12	0	0	0.60
1985/86	1.41	0.30	0	0	0.41
1986/87	2.29	0.53	1.17	0.13	0.53
1987/88	3.33	0.72	1.33	0.18	0.51
1988/89	6.30	1.13	1.78	0.23	0.43
1989/90	7.60	1.26	2.14	0.24	0.55
1990/91	7.34	1.28	2.03	0.22	0.72
1991/92	12.27	2.29	1.66	0.19	1.94
1992/93	12.46	2.60	0.25	0.03	2.15
1993/94	7.10	1.62	0.17	0.02	1.42
1994/95	3.57	0.84	0	0	1.73
1995/96	2.55	0.66	0	0	1.29
1996/97	0.54	0.15	0.10	0.01	1.34
1997/98	0.74	0.20	0.09	0.01	0.89
1998/99	0.70	0.19	0.08	0.01	0.57
1999/00	0.23	0.06	0.08	0.01	0.36
2000/01	0.17	0.04	0.09	0.01	0.46
2001/02	0.23	0.05	0.09	0.01	0.82
2002/03	0.34	0.07	0.11	0.01	0.48
2003/04	0.26	0.05	0.12	0.01	0.33
2004/05	0.21	0.04	0.14	0.02	0.47
2005/06	0.43	0.08	0.17	0.02	0.46
2006/07	0.62	0.10	0.19	0.02	0.55
2007/08	0.86	0.14	0.21	0.02	0.57
2008/09	0.66	0.11	0.22	0.02	0.49
2009/10	0.71	0.11	0.23	0.02	0.31
2010/11					

Table A-6. Predicted total (retained + discard) Tanner crab biomass (1000 t) from the directed plus all non-directed fisheries, 1973/74-2009/10. Post-release discard mortality rates applied (0.50=pot and 0.80=groundfish).

Year	Total Catch Biomass (1000 t)	
	Male	Female
1973/74	34.89	11.59
1974/75	31.86	5.72
1975/76	47.75	5.13
1976/77	60.77	6.64
1977/78	40.22	5.22
1978/79	36.93	5.34
1979/80	34.65	8.08
1980/81	21.22	5.54
1981/82	7.64	1.25
1982/83	3.31	0.65
1983/84	2.98	0.52
1984/85	1.62	0.50
1985/86	3.73	0.92
1986/87	6.05	1.25
1987/88	12.56	1.94
1988/89	25.95	2.93
1989/90	35.31	3.60
1990/91	35.00	4.88
1991/92	35.56	5.47
1992/93	19.16	3.38
1993/94	9.68	2.15
1994/95	6.42	1.54
1995/96	2.45	0.91
1996/97	1.28	0.66
1997/98	1.06	0.48
1998/99	0.49	0.25
1999/00	0.49	0.28
2000/01	0.73	0.47
2001/02	0.69	0.32
2002/03	0.55	0.23
2003/04	0.59	0.29
2004/05	1.51	0.36
2005/06	2.65	0.49
2006/07	3.12	0.54
2007/08	2.21	0.43
2008/09	1.78	0.32
2009/10		

Table A-7. Model estimates of population biomass and abundance, male, female and total mature biomass, abundance of legal (≥ 138mm) males, recruitment to the population, male mature biomass at mating, and full-selection fishing mortality rate. (Biomass in 1000t, abundance in 10^6 crab).

Year	Population ≥ 25mm		Mature Biomass (1000 t)			Males ≥ 138 mm	R > 25-30mm	MMB @Mating	Full-Selection F
	1000 t	10^6 crab	Female	Male	Total	10^6 crab	10^6 crab	1000 t	
1974/75	494.58	2514.92	121.56	242.88	364.43	109.49	111.60	175.08	0.309
1975/76	443.36	2130.23	114.40	221.12	335.52	101.37	309.80	160.66	0.332
1976/77	402.93	2253.96	107.92	197.19	305.11	87.38	150.69	125.92	0.668
1977/78	345.20	2020.92	95.34	162.61	257.95	64.80	143.43	85.79	1.343
1978/79	275.92	1798.17	79.71	120.36	200.07	41.98	47.68	68.45	1.239
1979/80	231.27	1454.24	70.98	93.38	164.36	31.23	26.25	47.83	1.675
1980/81	192.13	1138.96	65.85	64.62	130.47	16.78	99.40	27.19	3.740
1981/82	156.70	1018.75	56.59	44.67	101.26	7.72	43.25	23.93	3.007
1982/83	136.25	837.86	47.66	45.01	92.68	11.15	500.29	33.29	0.532
1983/84	144.53	1650.09	41.47	56.44	97.92	20.81	302.21	46.17	0.090
1984/85	155.50	1907.15	37.09	62.68	99.77	27.54	195.54	51.57	0.088
1985/86	169.72	1899.32	36.93	61.15	98.08	28.19	232.99	51.70	0.005
1986/87	195.21	1968.66	44.24	60.04	104.27	27.36	144.50	49.25	0.030
1987/88	223.97	1840.92	56.33	64.63	120.96	27.50	119.86	51.94	0.073
1988/89	250.38	1685.13	63.83	81.55	145.38	32.79	91.39	62.25	0.165
1989/90	262.10	1492.21	64.93	105.17	170.10	45.97	17.36	70.82	0.441
1990/91	244.69	1172.94	62.22	110.93	173.15	50.76	22.34	66.27	0.703
1991/92	206.74	917.92	56.60	95.84	152.44	41.75	27.75	54.25	0.687
1992/93	162.13	715.49	48.56	75.42	123.98	32.34	17.02	35.83	1.046
1993/94	113.72	529.42	38.89	49.93	88.83	19.93	24.45	27.51	0.798
1994/95	85.18	427.37	30.68	37.86	68.54	15.11	42.23	24.51	0.467
1995/96	68.50	400.75	24.60	31.72	56.32	13.69	31.25	21.70	0.322
1996/97	56.25	364.76	20.10	25.41	45.52	11.50	59.14	19.56	0.164
1997/98	51.13	400.32	17.18	21.86	39.04	9.94	21.97	17.74	0.036
1998/99	48.49	356.19	15.35	20.01	35.36	9.44	99.90	16.41	0.026
1999/00	49.75	478.28	14.43	18.97	33.39	9.07	47.40	16.01	0.018
2000/01	52.71	472.42	14.21	19.56	33.77	9.24	139.28	16.52	0.021
2001/02	59.51	651.34	14.39	21.39	35.78	10.17	49.35	17.88	0.030
2002/03	65.65	611.68	15.21	23.61	38.82	11.34	72.02	19.91	0.018
2003/04	73.55	626.79	16.95	26.51	43.47	12.79	109.47	22.55	0.013
2004/05	83.51	714.61	19.21	30.60	49.81	14.49	28.64	26.04	0.015
2005/06	91.60	622.34	21.25	36.51	57.76	17.34	19.28	30.38	0.056
2006/07	96.45	529.12	22.11	42.60	64.71	20.42	22.27	34.62	0.098
2007/08	97.24	459.38	22.61	47.26	69.87	23.25	23.69	38.22	0.098
2008/09	94.06	406.14	22.31	49.35	71.65	24.63	90.65	40.80	0.062
2009/10	90.83	499.46	20.33	50.66	70.99	25.46	146.45	42.35	0.040
2010/11	88.84	686.07	17.80	50.96	68.76	26.70			

Table A-8. Parameters values and whether parameters were estimated in the model, excluding recruitments and fishing mortality parameters.

Parameter	Value	Standard Deviation	Estimated? (N=No, Y=Yes)
Natural Mortality – male and female crab	0.23		N
Female (a) parameter of exponential growth	1.76		N
Female (b) parameter of exponential growth	0.91		N
Male (a) parameter of exponential growth	1.55		N
Male (b) parameter of exponential growth	0.95		N
Alpha for gamma distribution of recruits	11.50		N
Beta for gamma distribution of recruits	4.0		N
Beta for gamma distribution female growth	0.75		N
Beta for gamma distribution male growth	0.75		N
Fishery selectivity total male slope	0.11	0.00	Y
Fishery selectivity total male length at 50%	136.89	0.23	Y
Fishery selectivity retention curve males slope	0.84	0.08	Y
Fishery selectivity retention curve males length at 50%	137.63	0.14	Y
Directed Fishery discard selectivity female slope	0.17	0.01	Y
Directed Fishery discard selectivity female length at 50%	107.32	1.23	Y
Snow crab fishery male selectivity slope ascending	0.20	0.01	Y
Snow crab fishery male selectivity length at 50% ascending	96.26	0.70	Y
Snow crab fishery male selectivity slope descending	0.46	0.06	Y
Snow crab fishery male selectivity length at 50% descending	138.58	0.40	Y
Snow crab fishery female selectivity slope	0.10	0.00	Y
Snow crab fishery female selectivity length at 50%	98.81	1.55	Y
Red king crab fishery male selectivity slope	0.18		N
Red king crab fishery male selectivity length at 50%	110.00		N
Red king crab fishery female selectivity slope	0.28		N
Red king crab fishery female selectivity length at 50%	95.00		N
Groundfish Fishery male selectivity slope	0.09	0.01	Y
Groundfish Fishery male selectivity length at 50%	60.76	1.62	Y
Groundfish Fishery female selectivity slope	0.02	0.00	Y
Groundfish Fishery female selectivity length at 50%	118.84	6.61	Y
Survey Q 1974-1981 – male	0.82	0.04	Y
Survey 1974-1981 length at 95% of Q – male	92.03	12.68	Y
Survey 1974-1981 length at 50% of Q – male	53.83	3.75	Y
Survey Q 1982-2010 – male	0.88		N
Survey 1982-2010 length at 95% of Q – male	120.00		N
Survey 1982-2010 length at 50% of Q – male	37.33	2.78	Y
Survey Q 1974-1981 – female	1.00	0.00	Y
Survey 1974-1981 length at 95% of Q – female	190.45	16.79	Y
Survey 1974-1981 length at 50% of Q – female	82.03	4.18	Y
Survey Q 1982-2010 – female	0.50	0.01	N
Survey 1982-2010 length at 95% of Q – female	120.0		N
Survey 1982-2010 length at 50% of Q – female	0		N
Fishery cpue q	0.00055		N

Table A-9. Likelihood values by component for the Tanner crab assessment model.

Likelihood Component	Likelihood
recruitment deviations	4.1
probability of maturity smooth constraint	5.2
Survey q penalty	29.4
F penalty	25.5
retained length	176.7
total directed length	167.7
female directed length	58.4
survey length	584.2
groundfish fishery length	916.5
snow fishery length	983.2
red king fishery length	-
survey biomass	395.6
fishery cpue	-
directed fishery male discard catch	2.8
directed fishery male retained catch	16.5
directed fishery female discard catch	12.2
groundfish fishery male + female catch	2.5
snow fishery male + female catch	40.5
red king fishery male + female catch	-
Total Likelihood	3420.90

Table A-10. Weighting factors for likelihood equations. Sample size for all length components was set at 200.

Likelihood Component	Weight Factor
Retained + discard male catch, male and female discards in snow and red king fisheries	10
directed fishery female discards	10
groundfish catch	10
total catch length composition	1.0
retained catch length composition	1.0
female directed fishery length composition	0.5
survey length composition	1.0
groundfish fishery length composition	0.5
snow and red king fishery length composition	1.0
survey biomass	1.0
recruitment deviations	1.0
fishing mortality deviations	5.0
fishery cpue	0.0

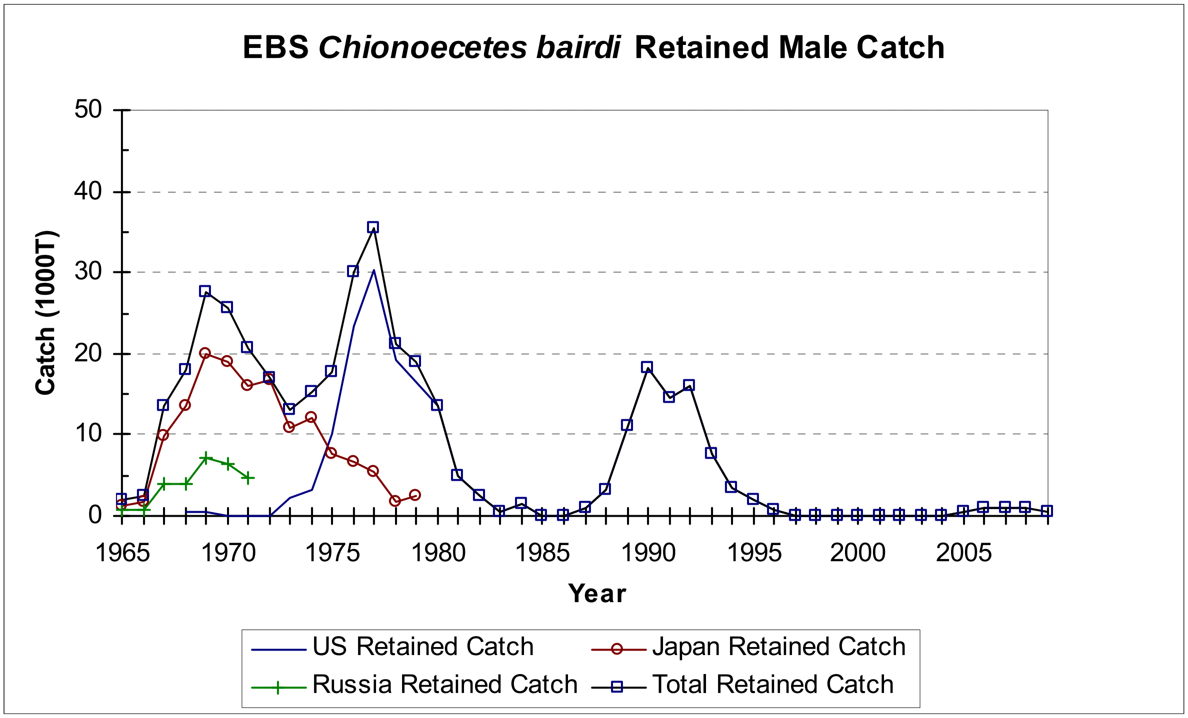


Figure A-1. Eastern Bering Sea *C. bairdi* retained male catch in the directed United States, Russian and Japanese fisheries, 1965/66-2009/10.

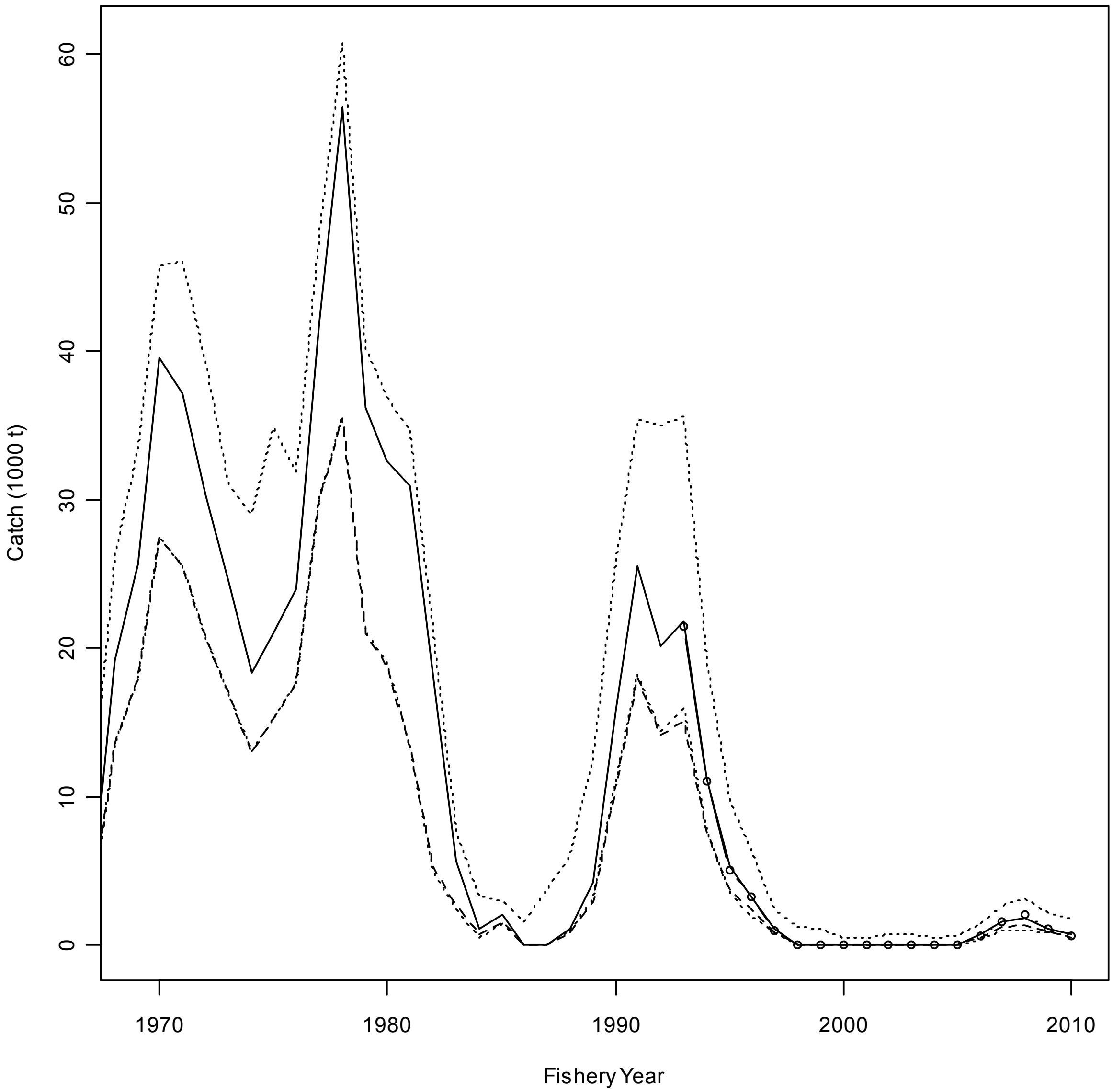


Figure A-2. Model predicted catch history of male Tanner crab catch by survey year (e.g., 2008 is the 2008/09 fishing year). [solid line=predicted retained plus discard catch in the directed fishery; dashed line=predicted retained catch in the directed fishery; dotted line=predicted total male catch from all sources].

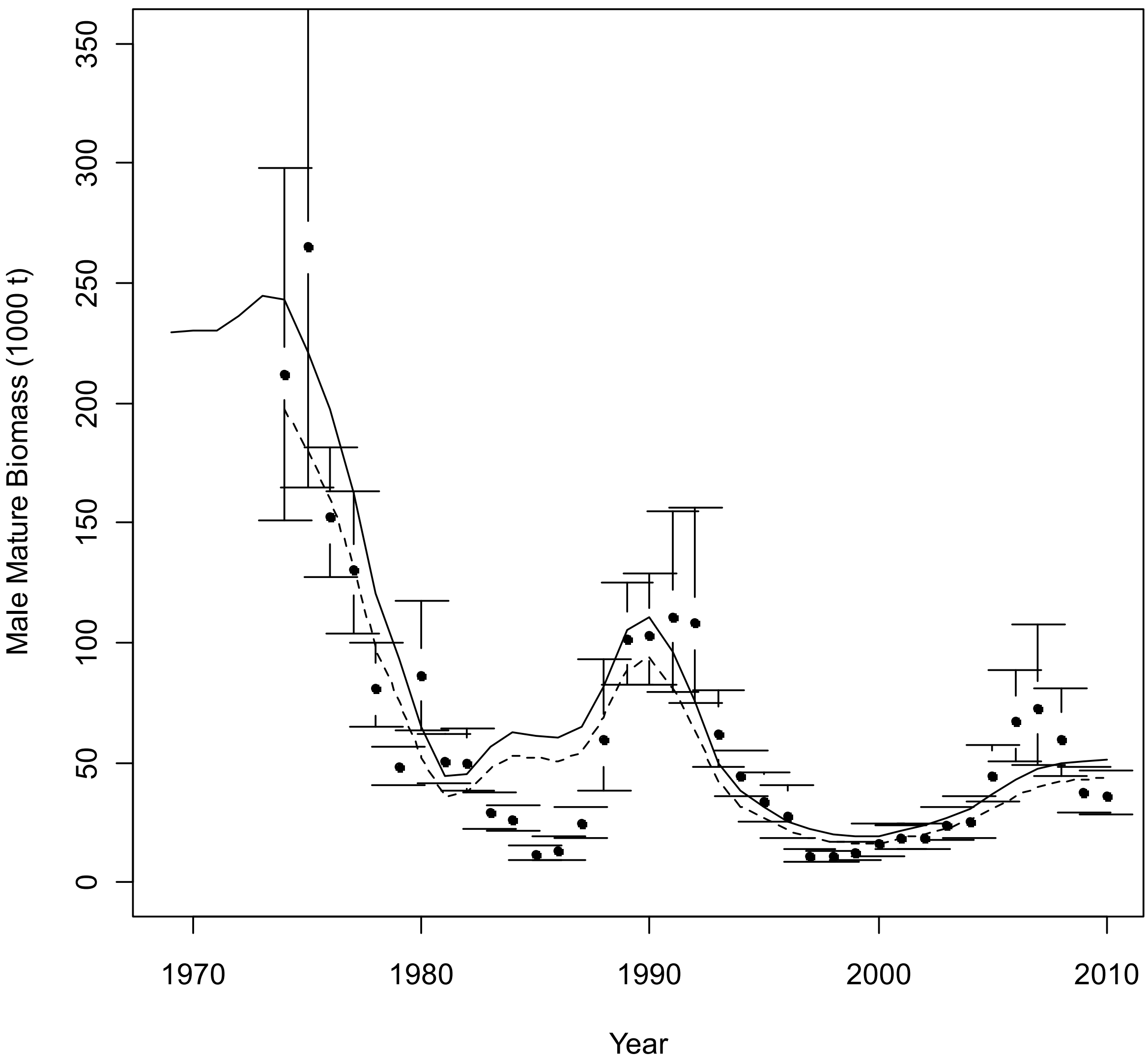


Figure A- 3. Population mature male biomass (millions of pounds, solid line) at the time of the survey, model estimate of survey mature biomass (dotted line) and observed survey mature male biomass with approximate lognormal 95% confidence intervals.

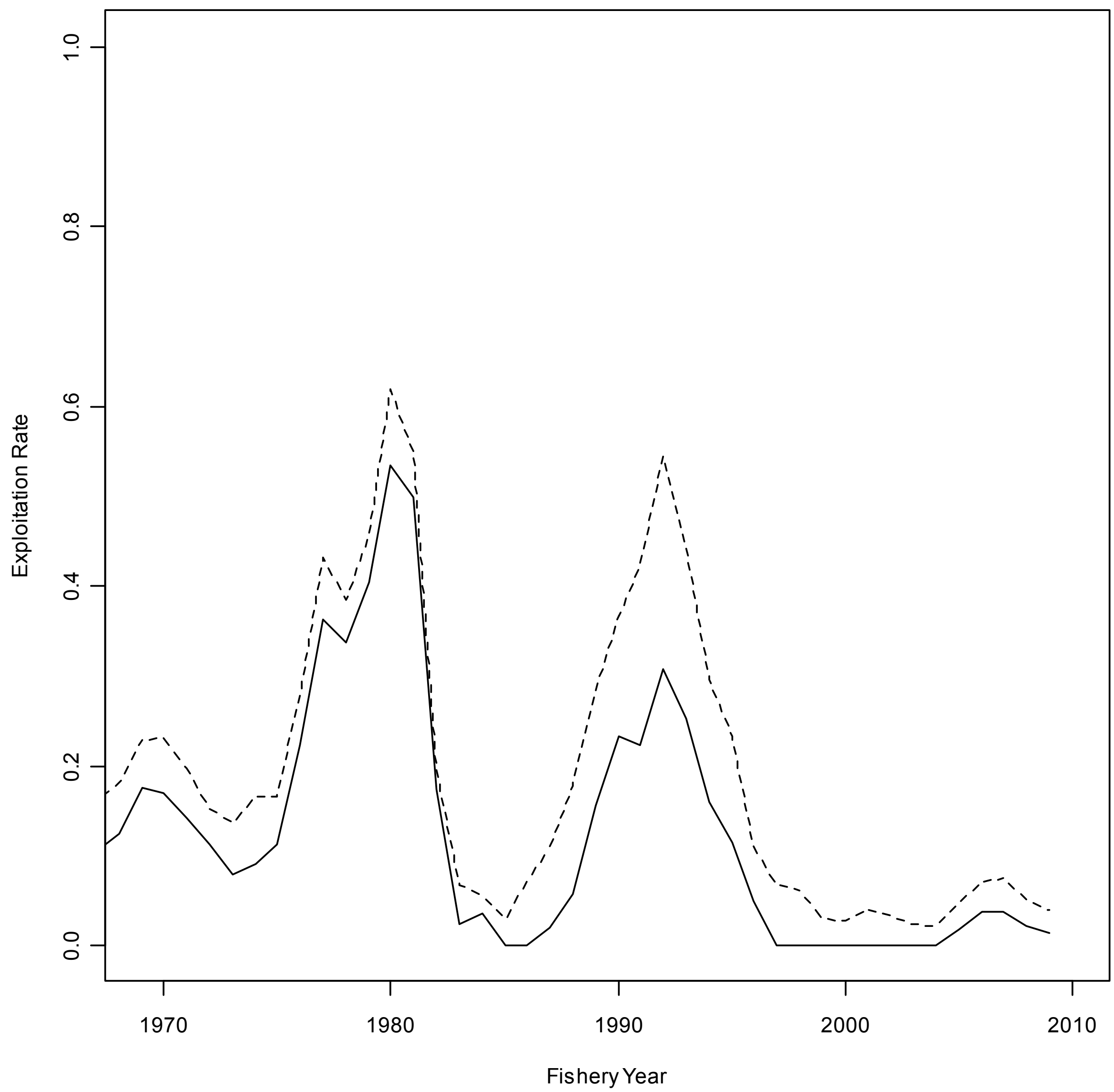


Figure A-4. Exploitation fraction estimated as the predicted catch biomass of legal males in all fisheries divided by the estimated legal male biomass at the time of the fishery (solid), and the predicted total catch (retained plus discard) divided by the estimated male mature biomass at the time of the fishery (dotted). Year is the year of the fishery.

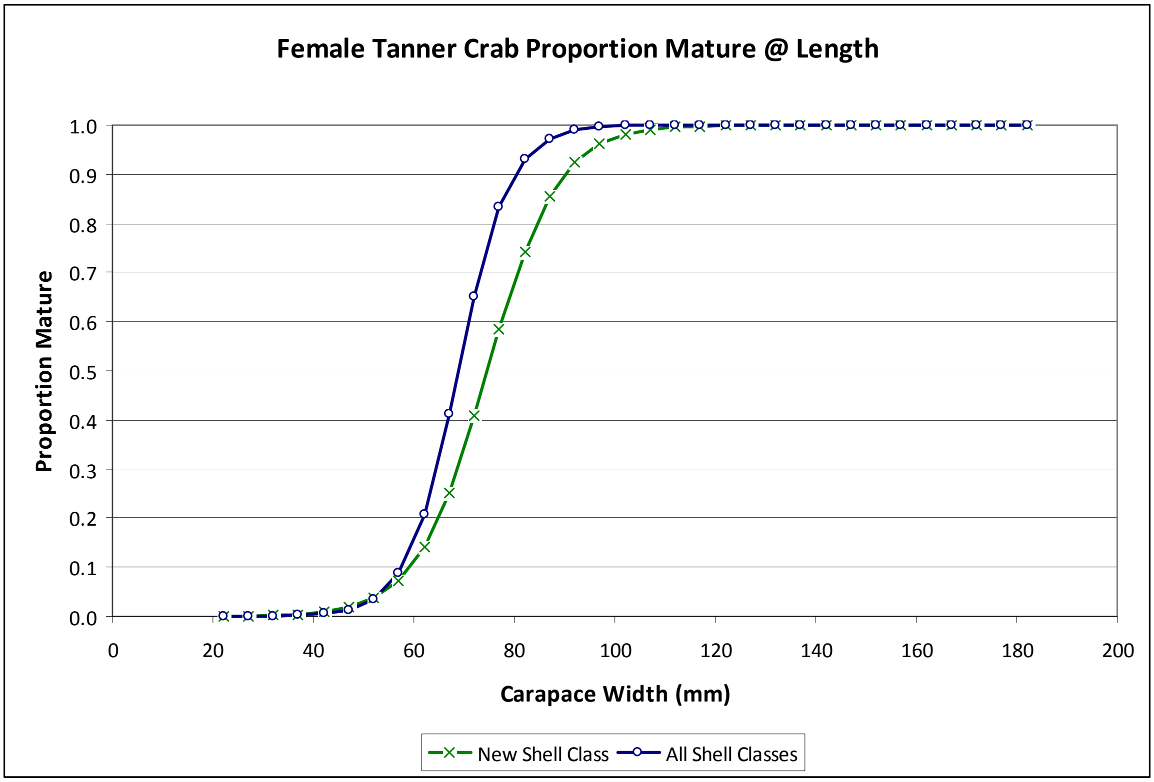


Figure A-5. Fitted logistic functions of proportion mature in the stock for new shell and old shell female Tanner crab based on egg code classification of new and old shell crab in 1976-2009 survey data.

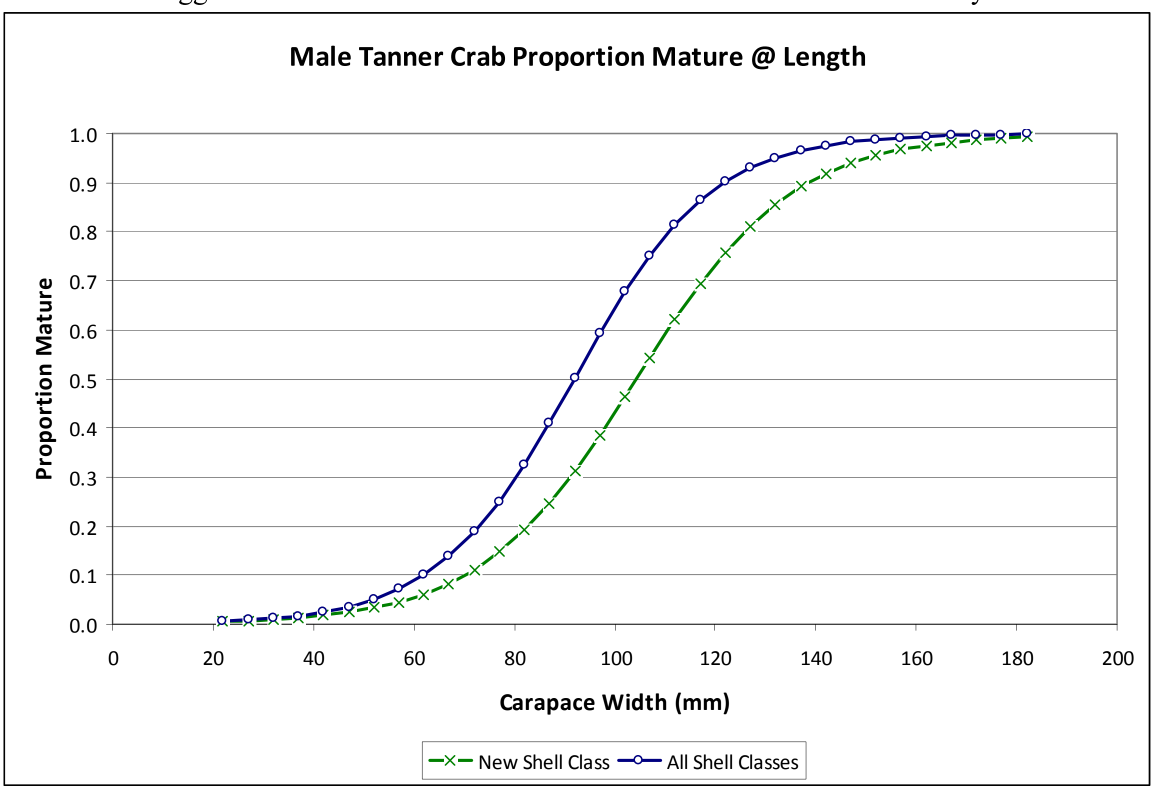


Figure A-6. Fitted logistic functions of proportion mature in the stock for new shell and old shell male Tanner crab based on classification of new and old shell crab in 1990-2007 survey data.

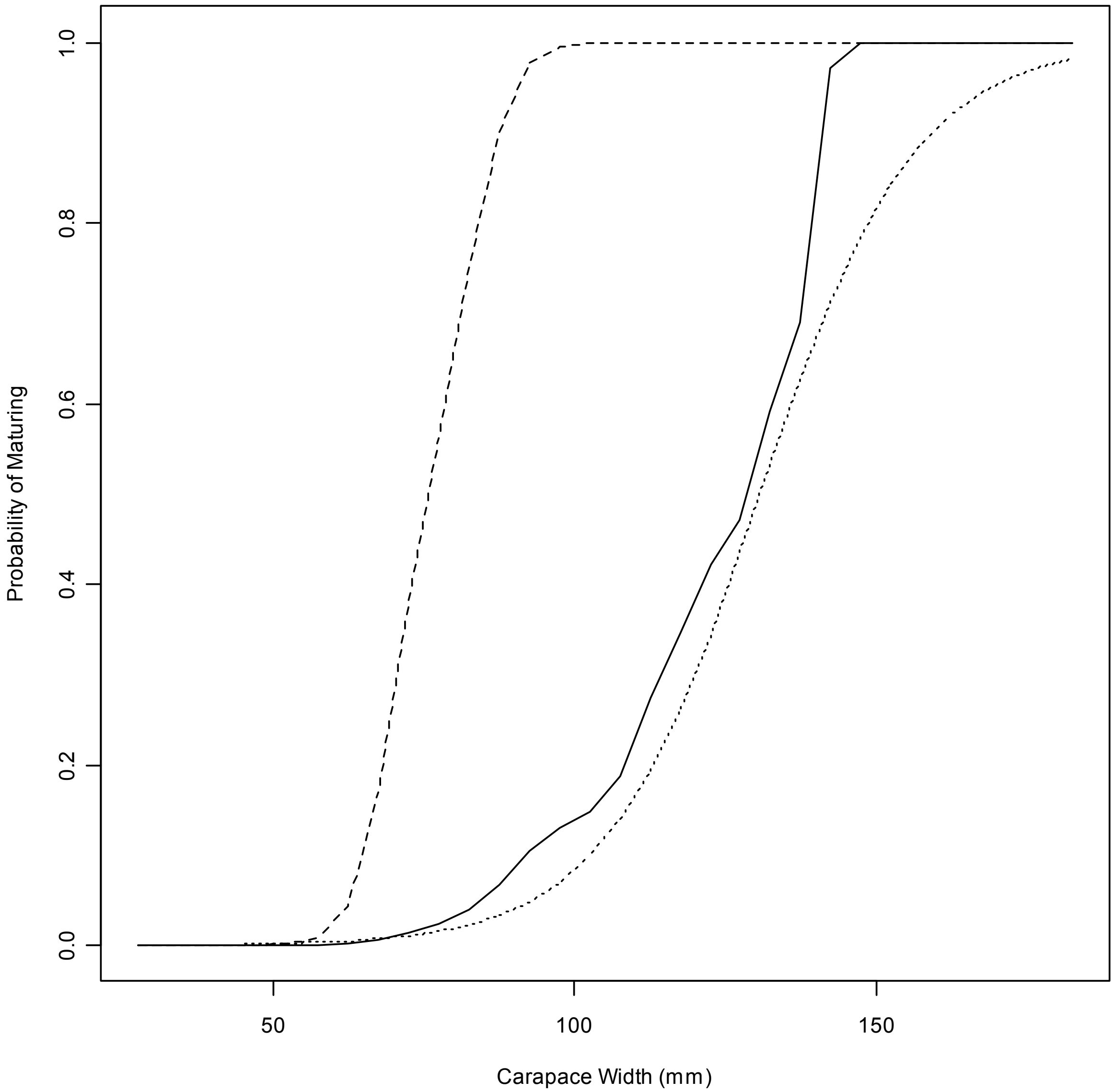
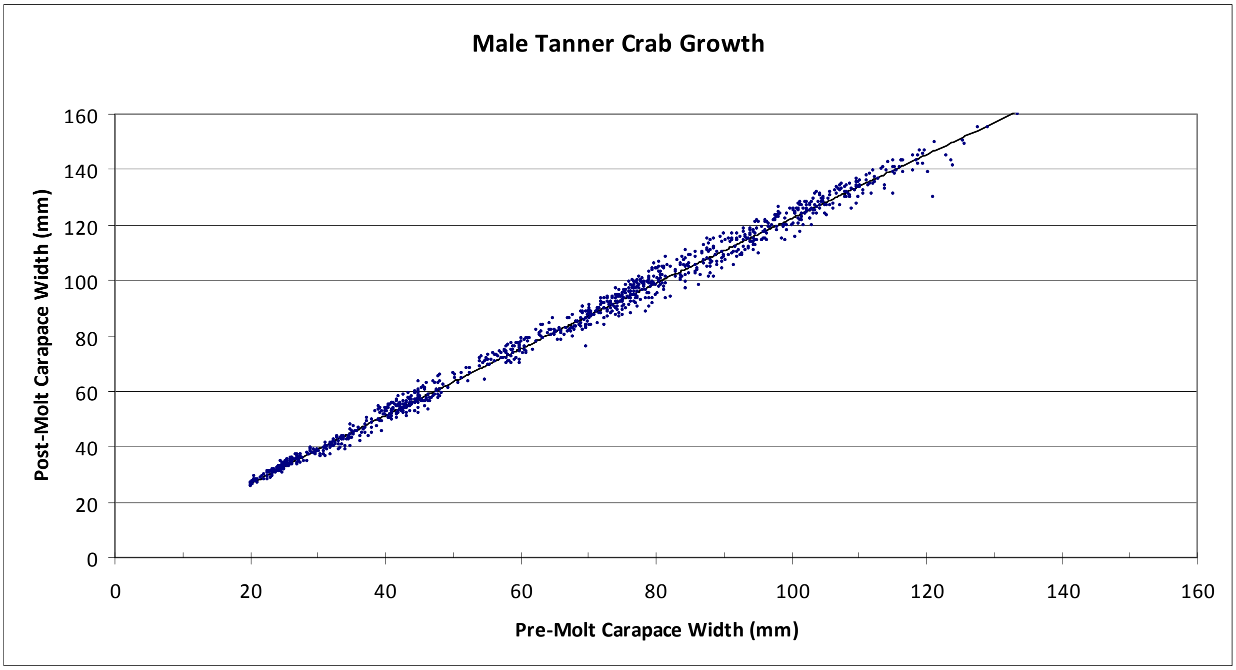


Figure A-7. Model estimate of probability of maturing by size for male (solid) and female (dashed) Tanner crab (not average fraction mature), and male probability of maturing by size used in Amendment #24 OFL analysis (dotted) (NPFMC 2007).

(a)



(b)

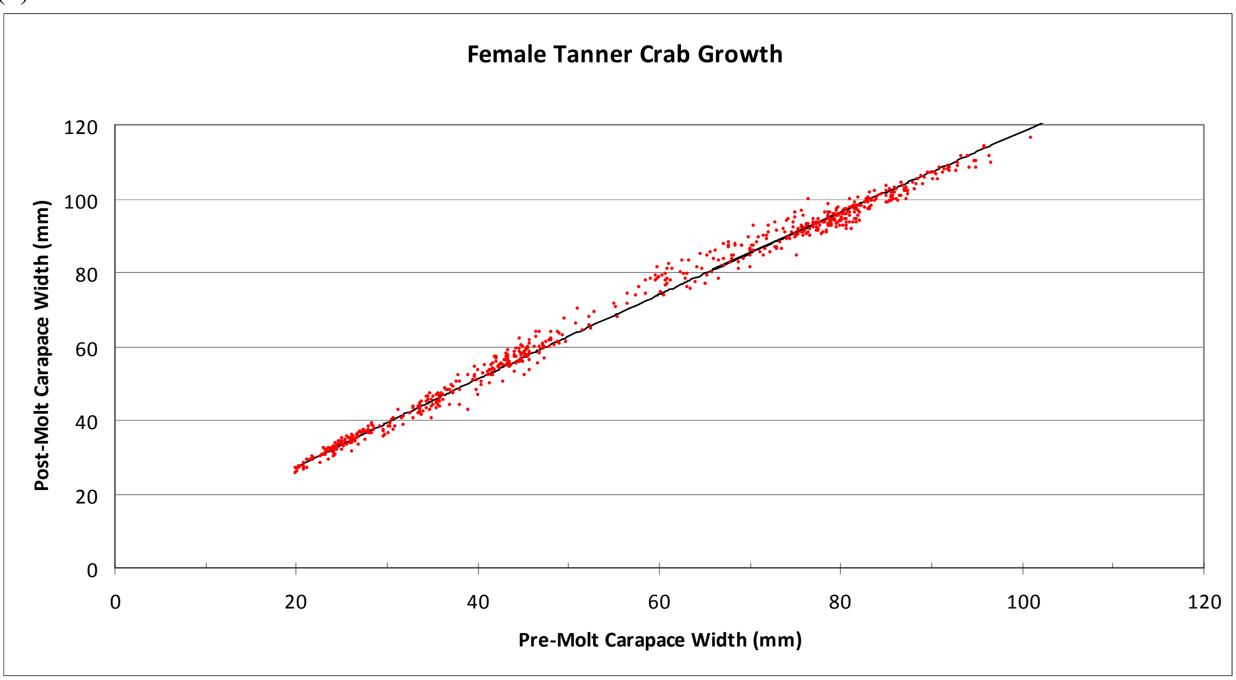


Figure A- 8. Growth of male (a) and female (b) Tanner crab as a function of premolt size. Estimated by Rugolo and Turnock 2010 based on data from GOA Tanner crab (Munk, unpublished data).

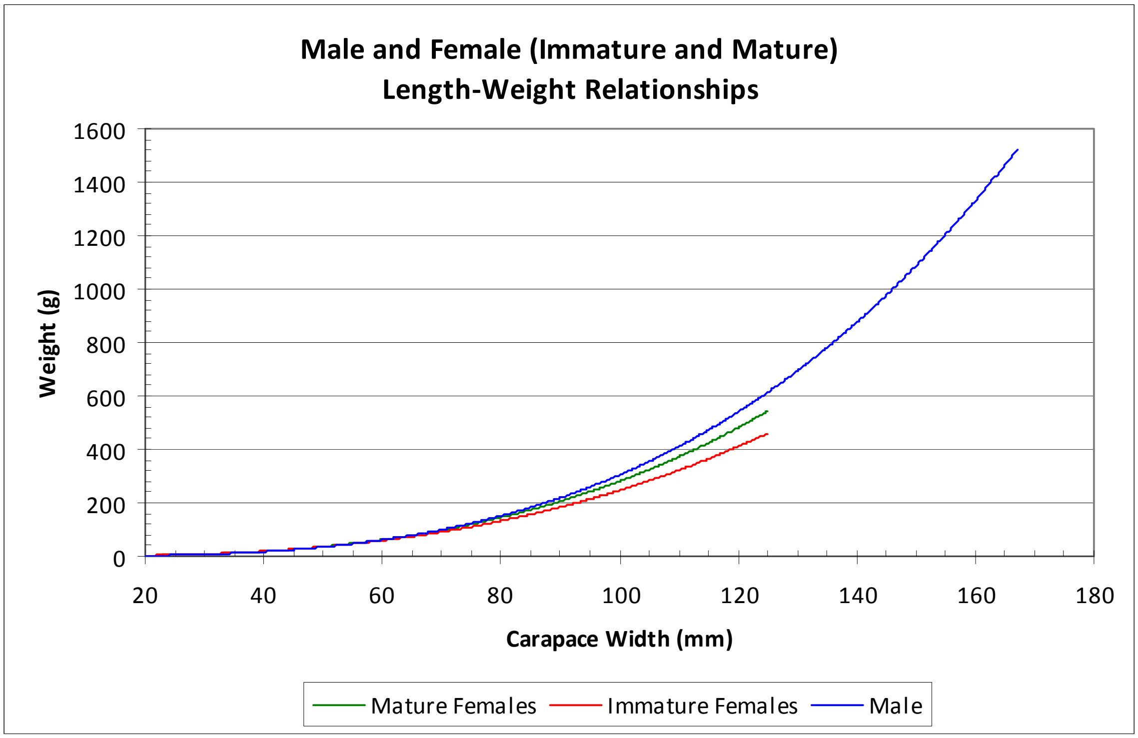


Figure A- 9. Weight (kg) – size (mm) relationship for male (top), mature female (middle) and immature female (bottom) Tanner crab.

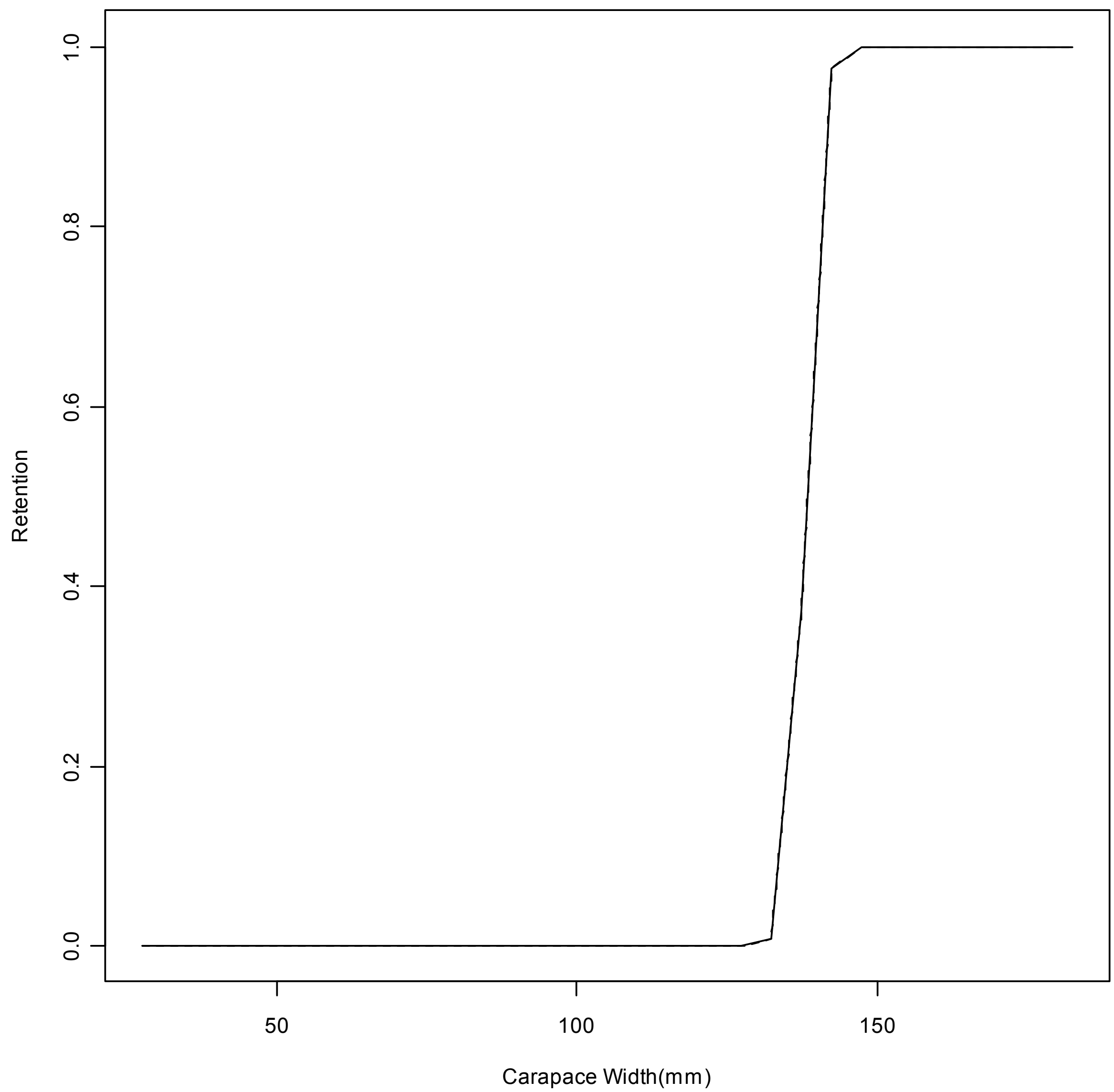


Figure A- 10. Model estimated fraction of the total catch that is retained (retention function) by size for male Tanner crab in th directed fishery all shell conditions combined. This retention function is multiplied by the total directed male selectivity curve to estimate the directed fishery retained selectivity.

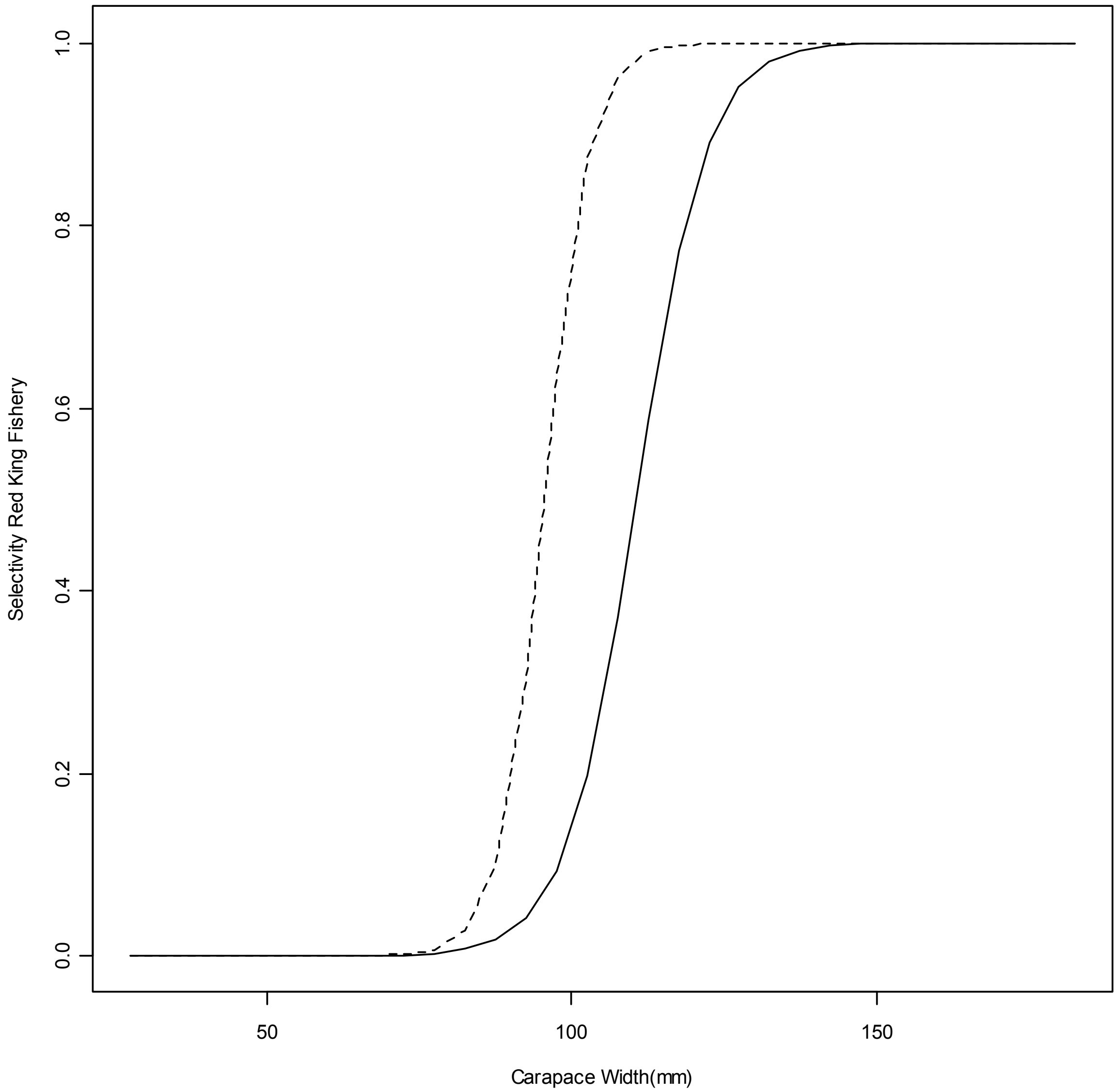


Figure A- 11. Selectivity curve estimated by the model for bycatch in the Bristol Bay red king crab fishery for females (dotted) and males (solid).

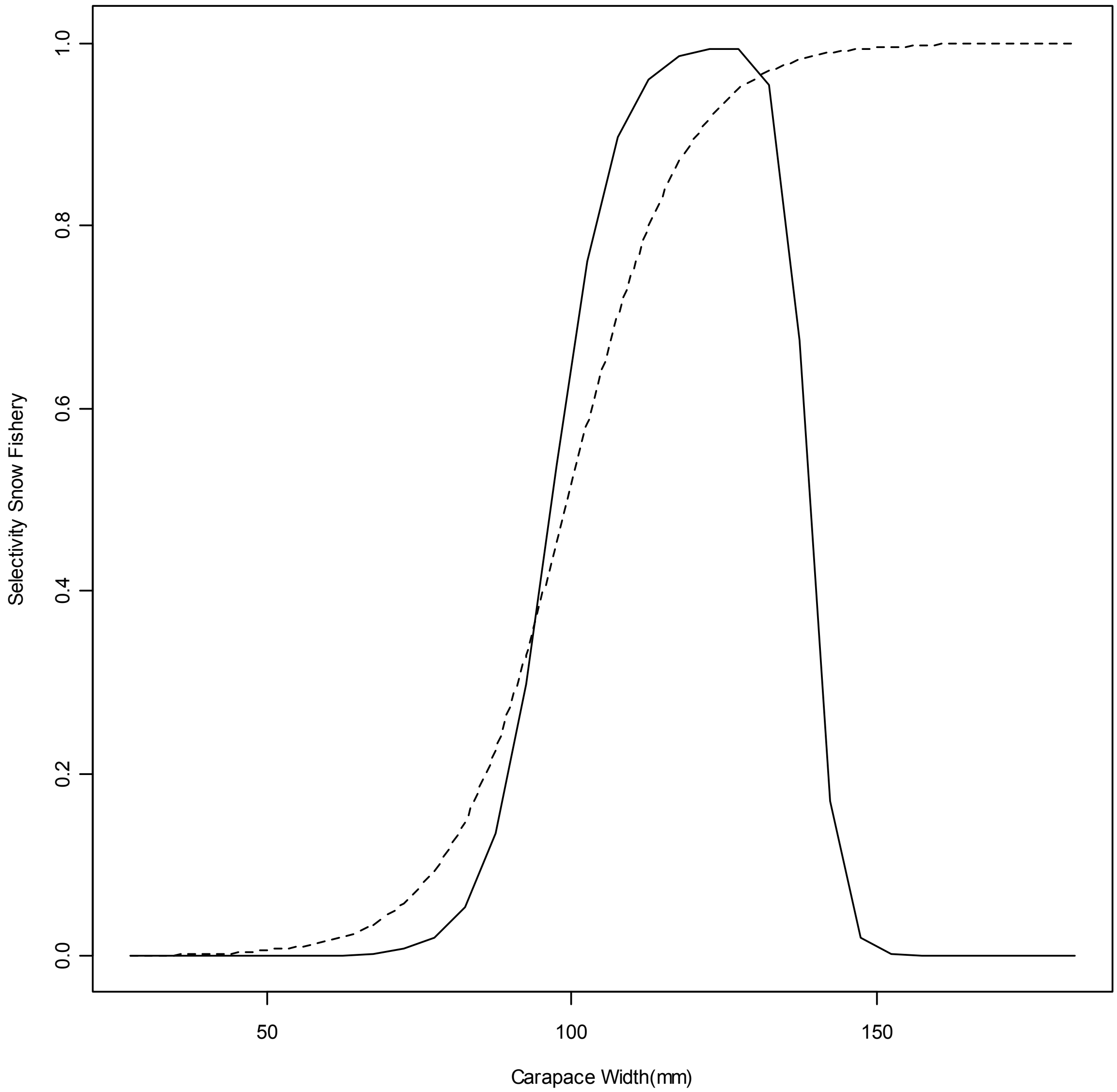


Figure A- 12. Selectivity curve estimated by the model for bycatch in the snow crab fishery for females (dotted) and males (solid).

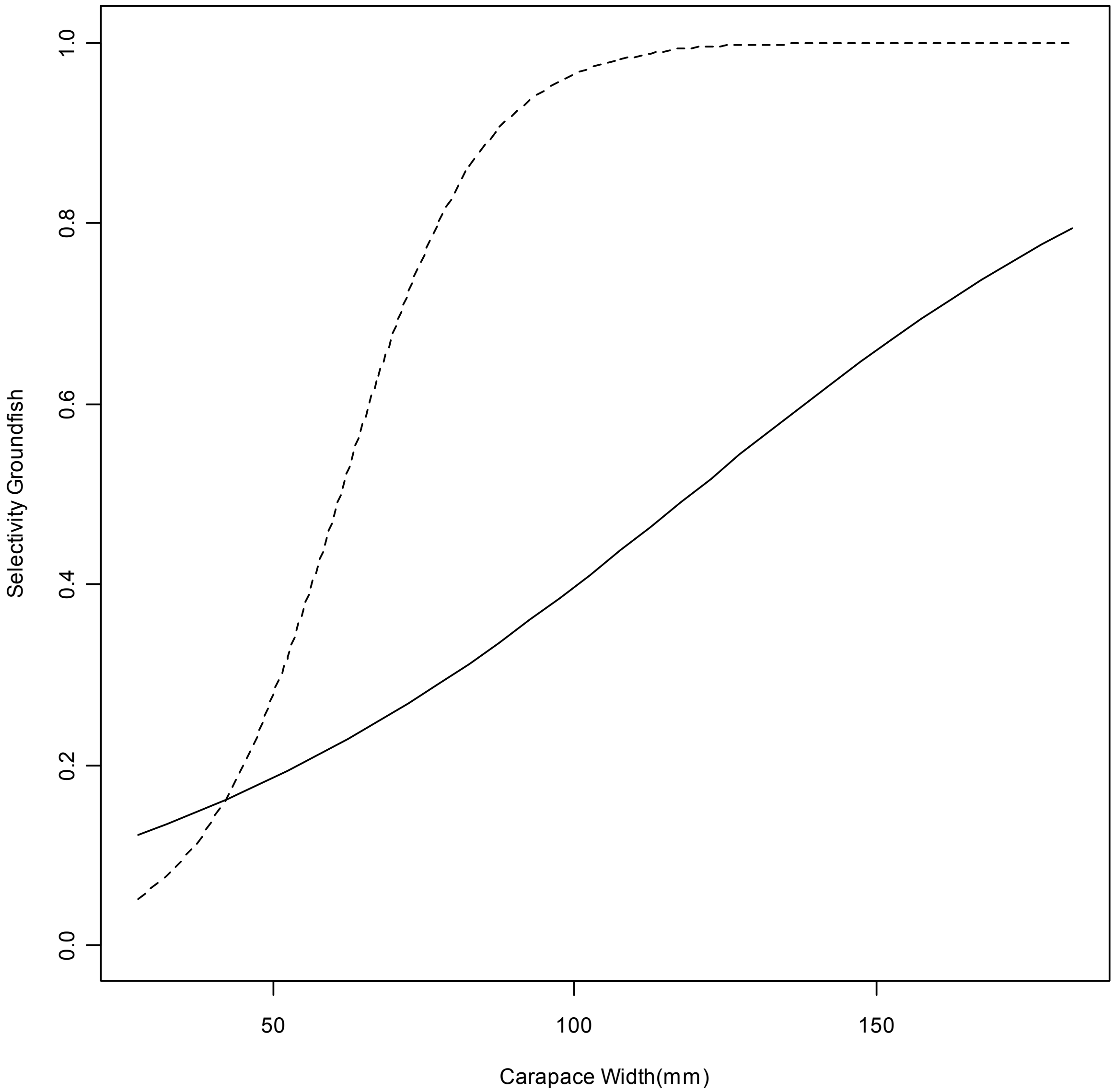


Figure A- 13. Selectivity curve estimated by the model for bycatch of males and females combined in the groundfish fishery.

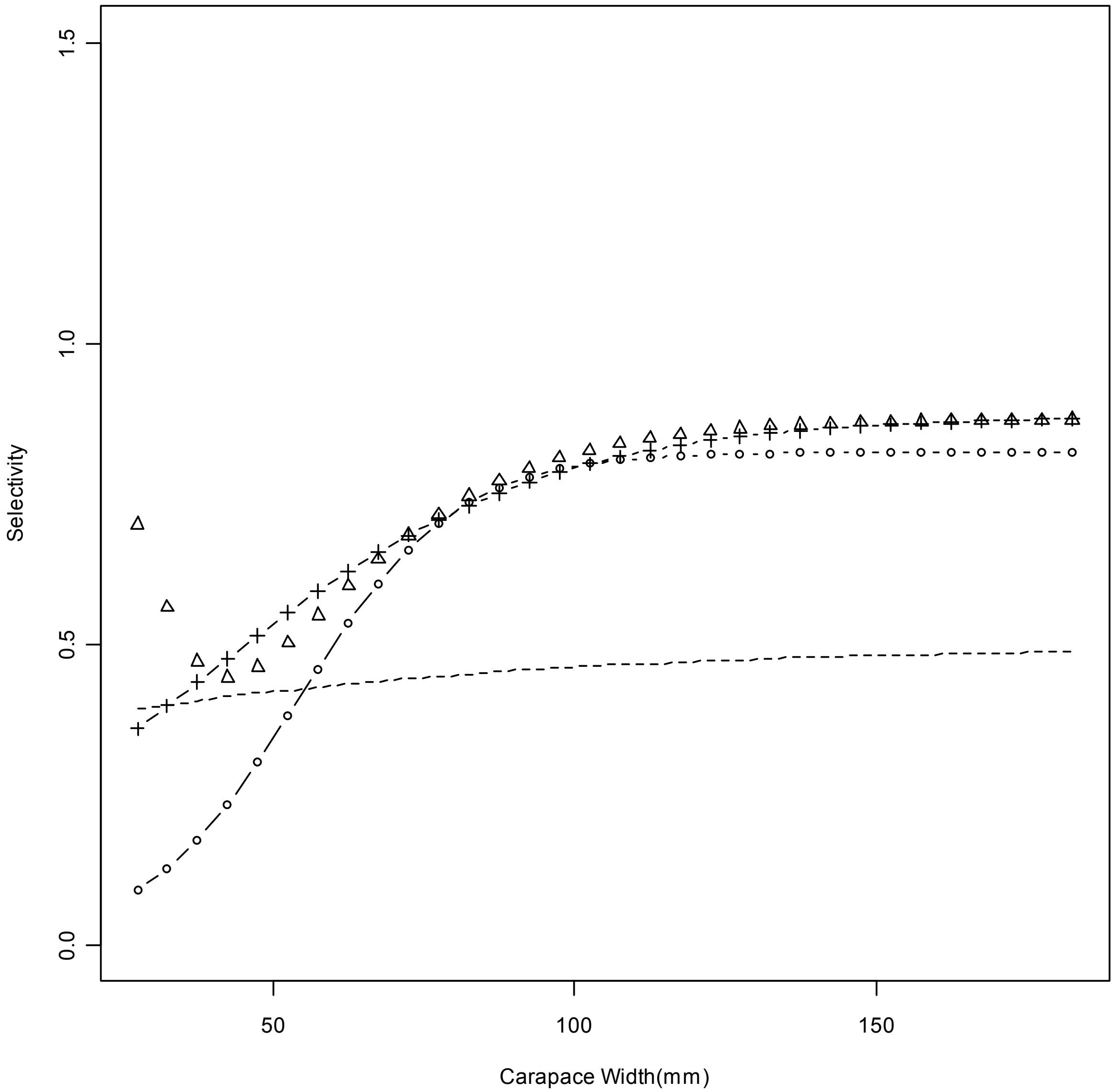


Figure A-14. Survey selectivity curves for male Tanner crab estimated for 1974-1981 (dashed line with circles), and 1982-2010 (dashed line with pluses). Survey selectivity estimated by Somerton and Otto (1998) are triangle symbols, and female selectivity for 1982-2010 is dashed line for reference.

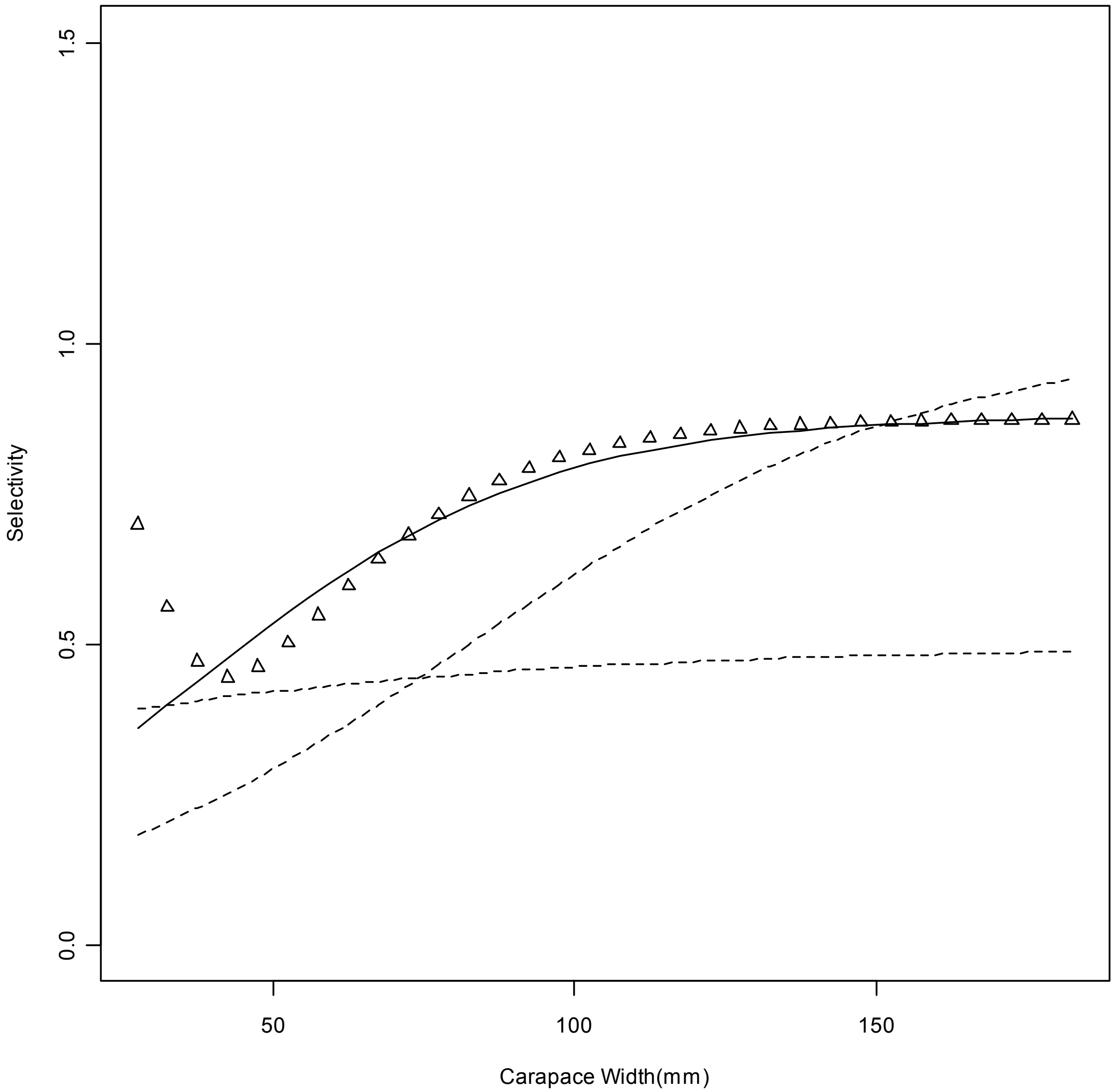


Figure A-15. Survey selectivity curves for female Tanner crab estimated for 1974-1981 (lower dashed line), and 1982-2010 (upper dashed line). Survey selectivity estimated by Somerton and Otto (1998) are triangle symbols, and male selectivity for 1982-2010 is solid line for reference.

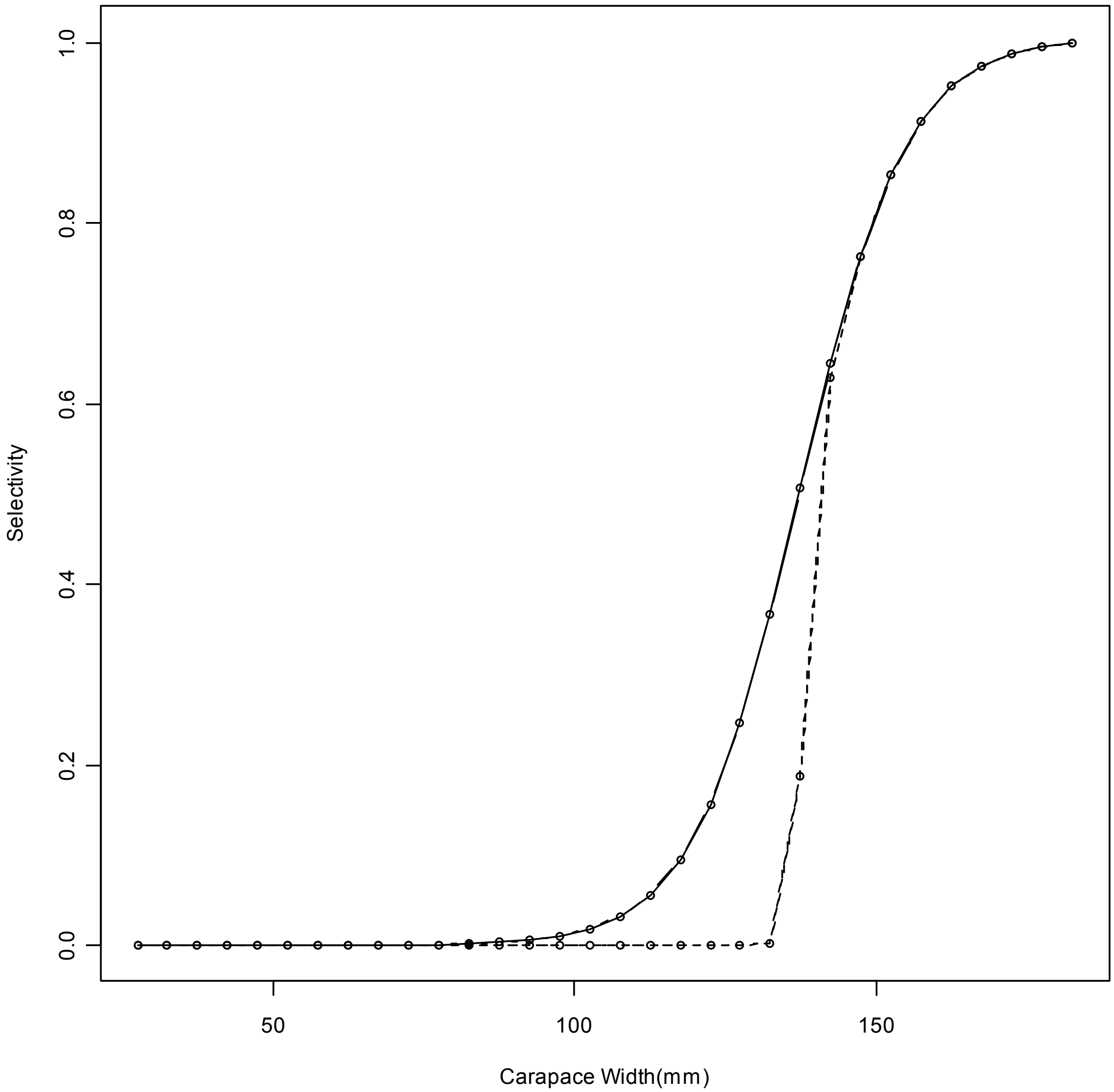


Figure A- 16. Selectivity curve for total catch (discard plus retained, solid line) and retained catch (dotted line) for combined shell condition male Tanner crab.

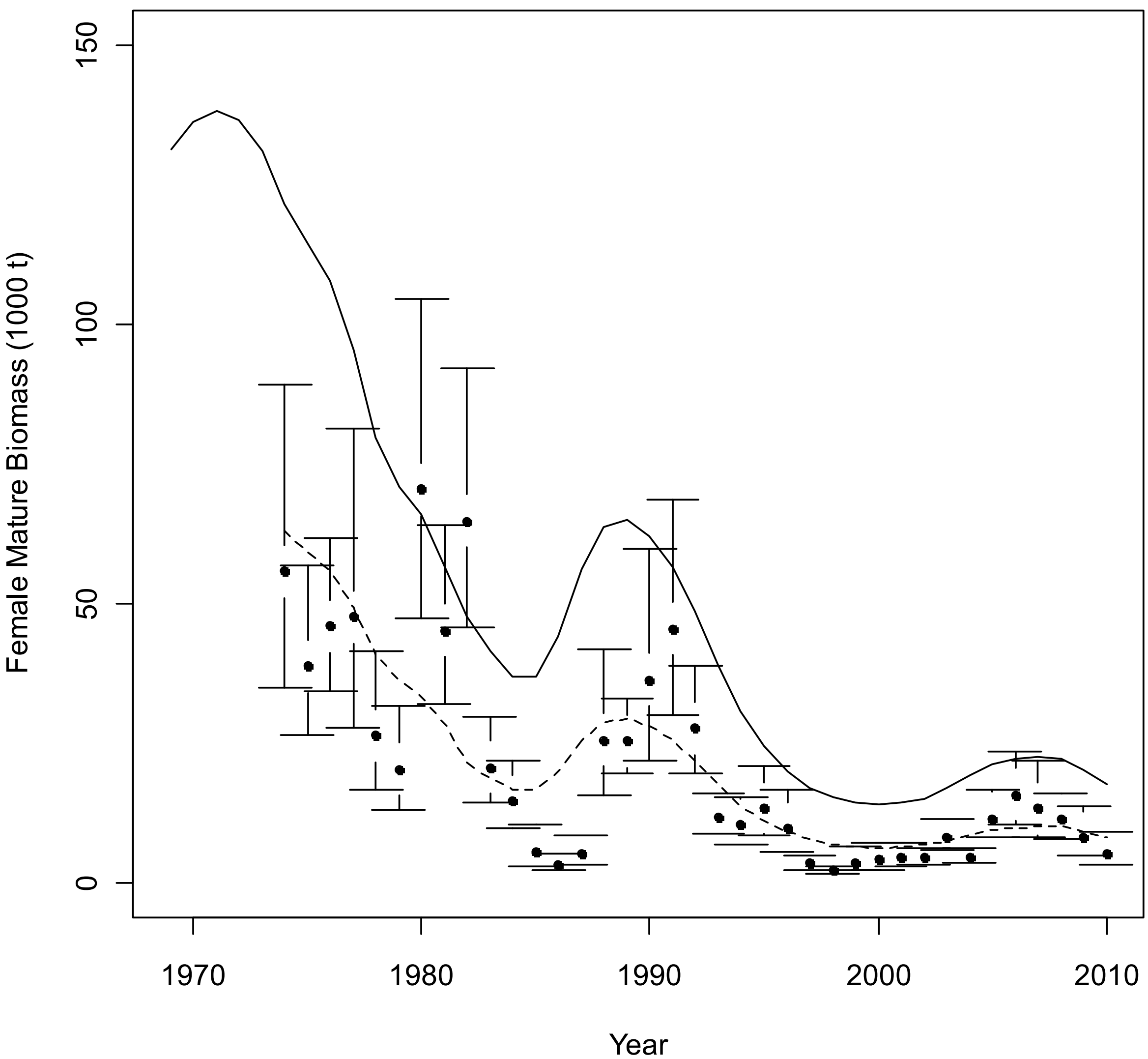


Figure A-17. Population female mature biomass (millions of pounds, solid line), model estimate of survey female mature biomass (dotted line) and observed survey female mature biomass with approximate lognormal 95% confidence intervals.

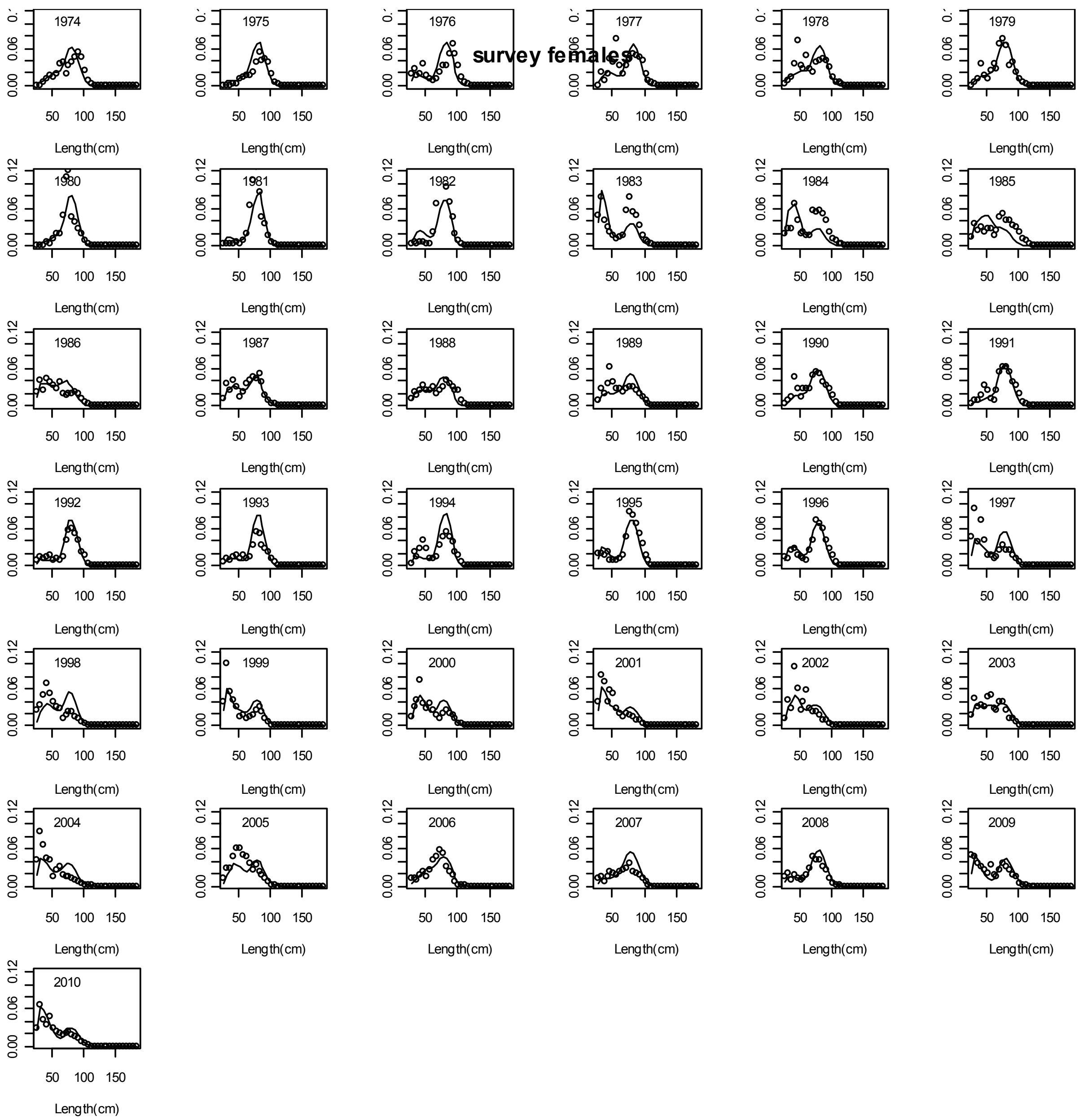


Figure A- 18. Model fit to the survey female size frequency data. Circles are observed survey data. Solid line is the model fit.

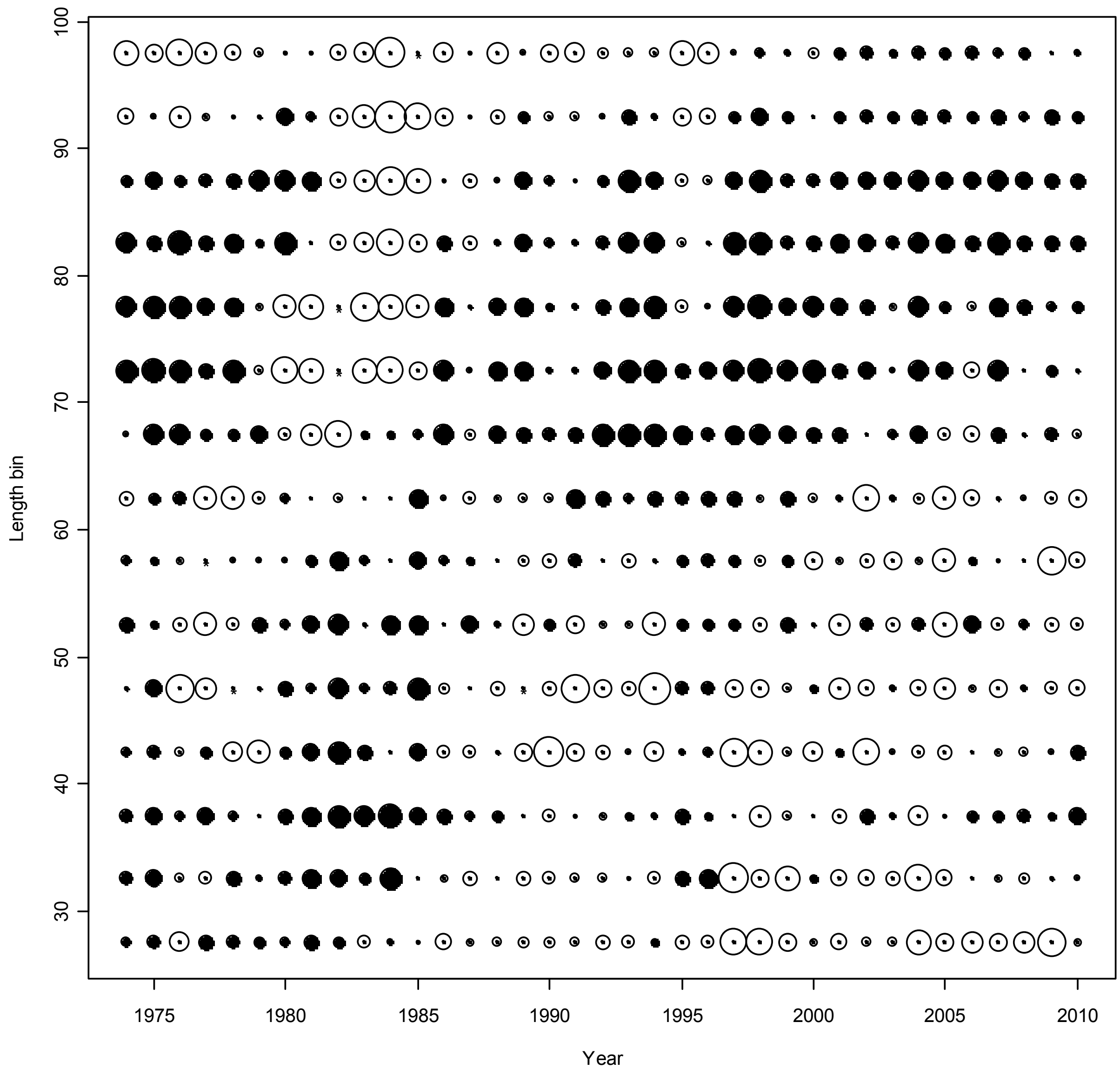


Figure A-19. Residuals of the model fit to the survey female size frequency data. Solid circles= overestimate and open circles=underestimate. Diameter of circle proportional to extent of lack of fit.

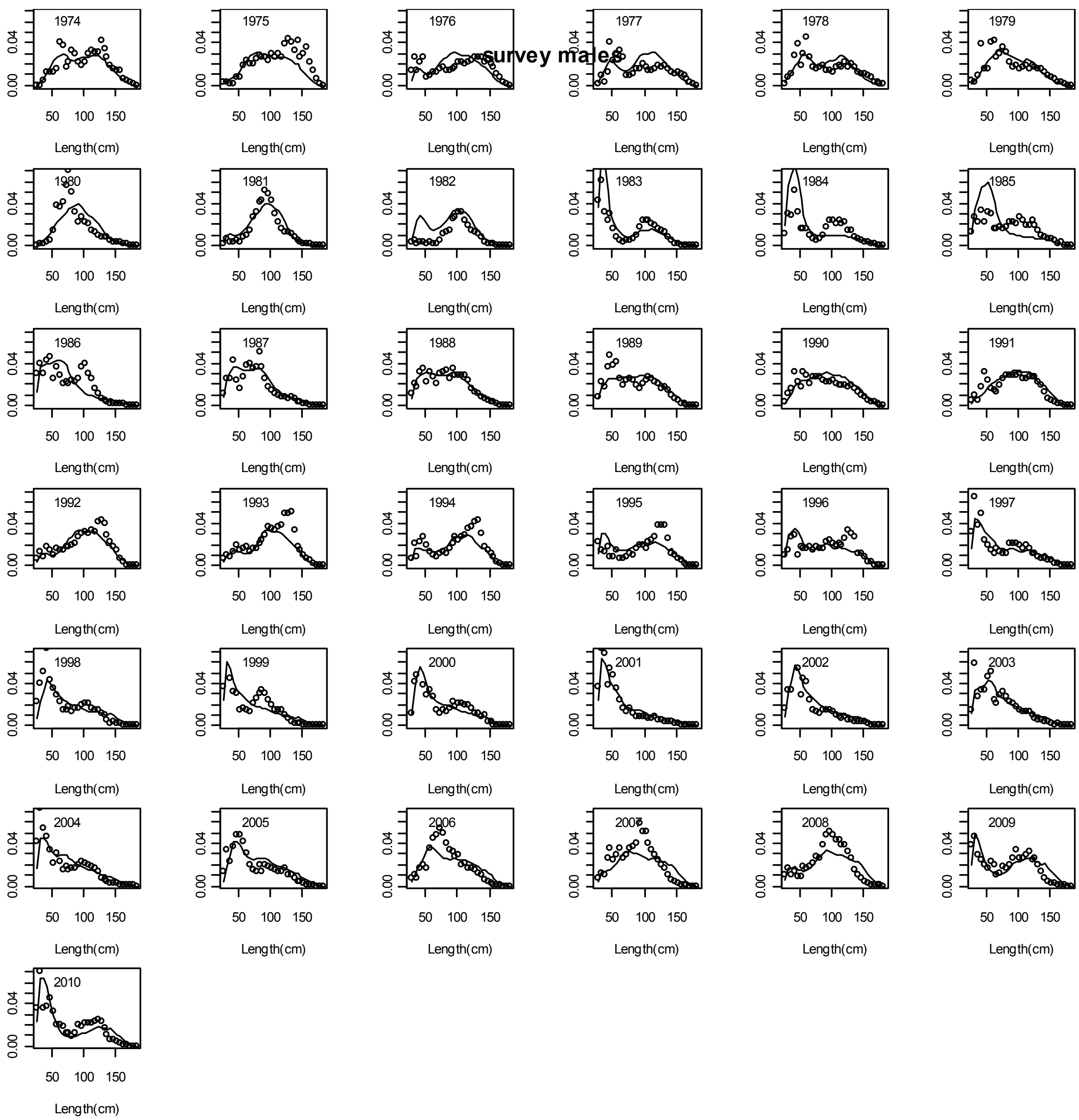


Figure A-20. Model fit to the survey male size frequency data. Circles are observed survey data. Solid line is the model fit.

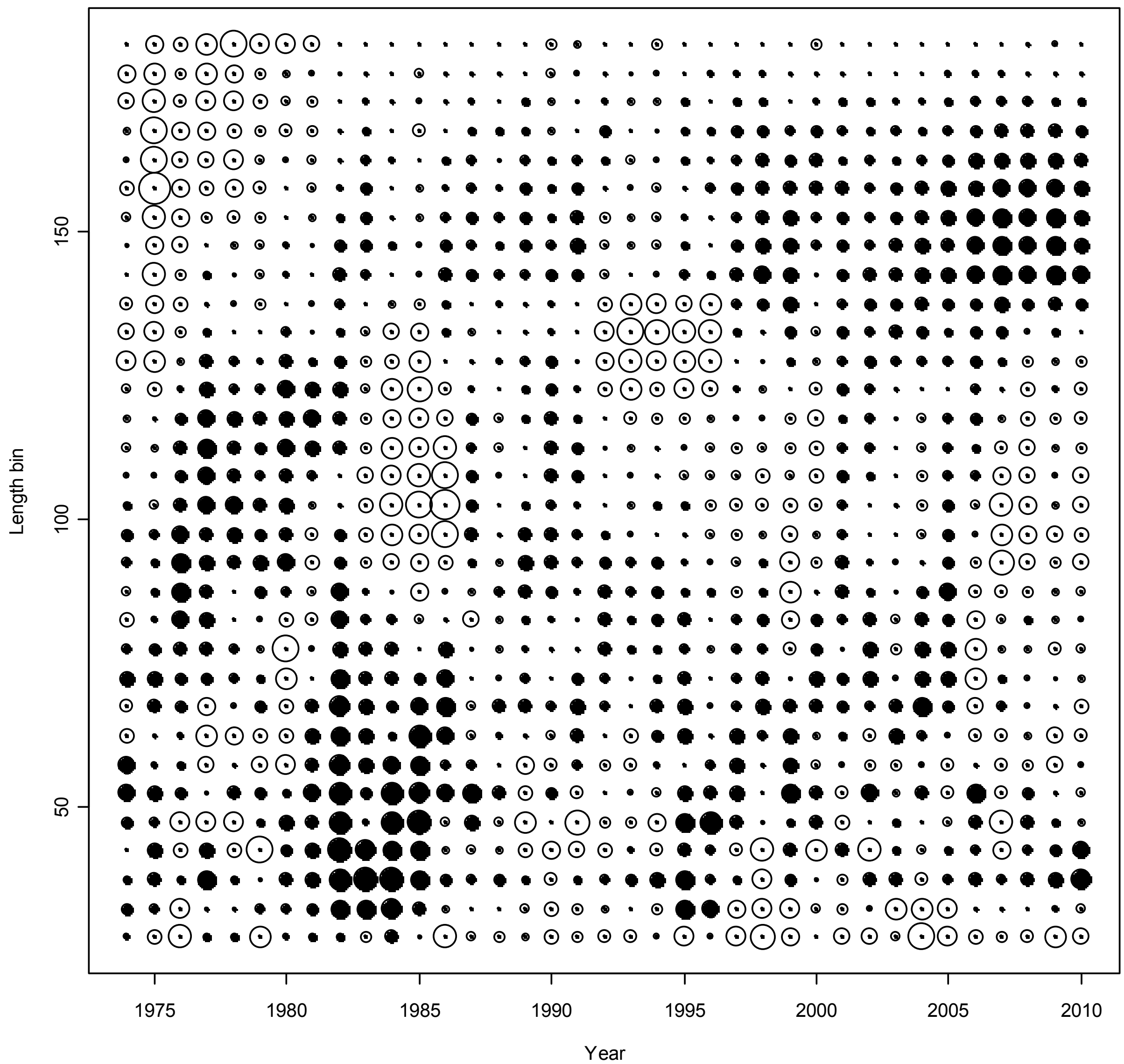


Figure A-21. Residuals of the model fit to the survey male size frequency data. Solid circles= overestimate and open circles=underestimate. Diameter of circle proportional to extent of lack of fit.

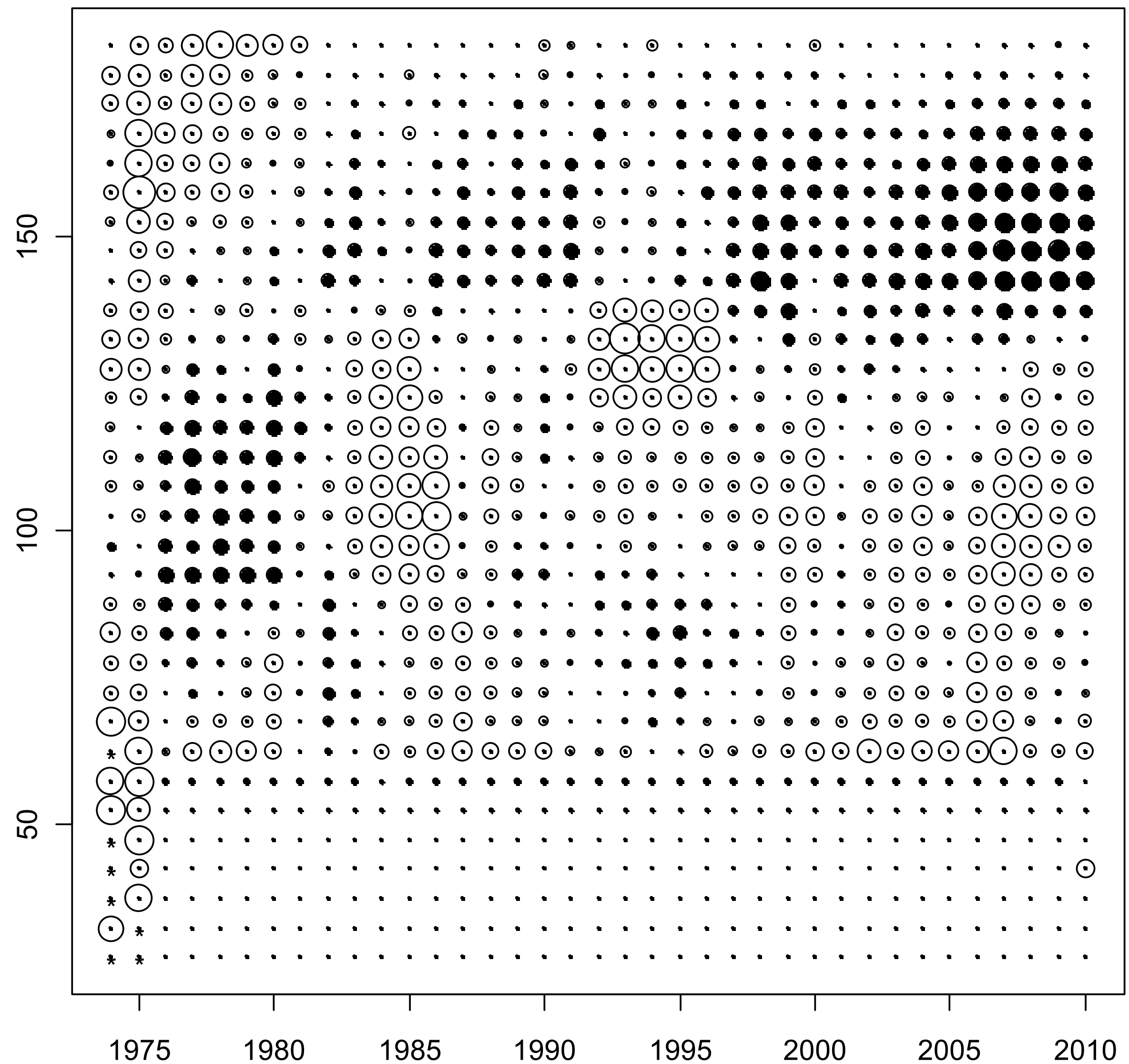


Figure A-22. Residuals of the model fit to the survey mature male size frequency data. Solid circles= overestimate and open circles=underestimate. Diameter of circle proportional to extent of lack of fit.

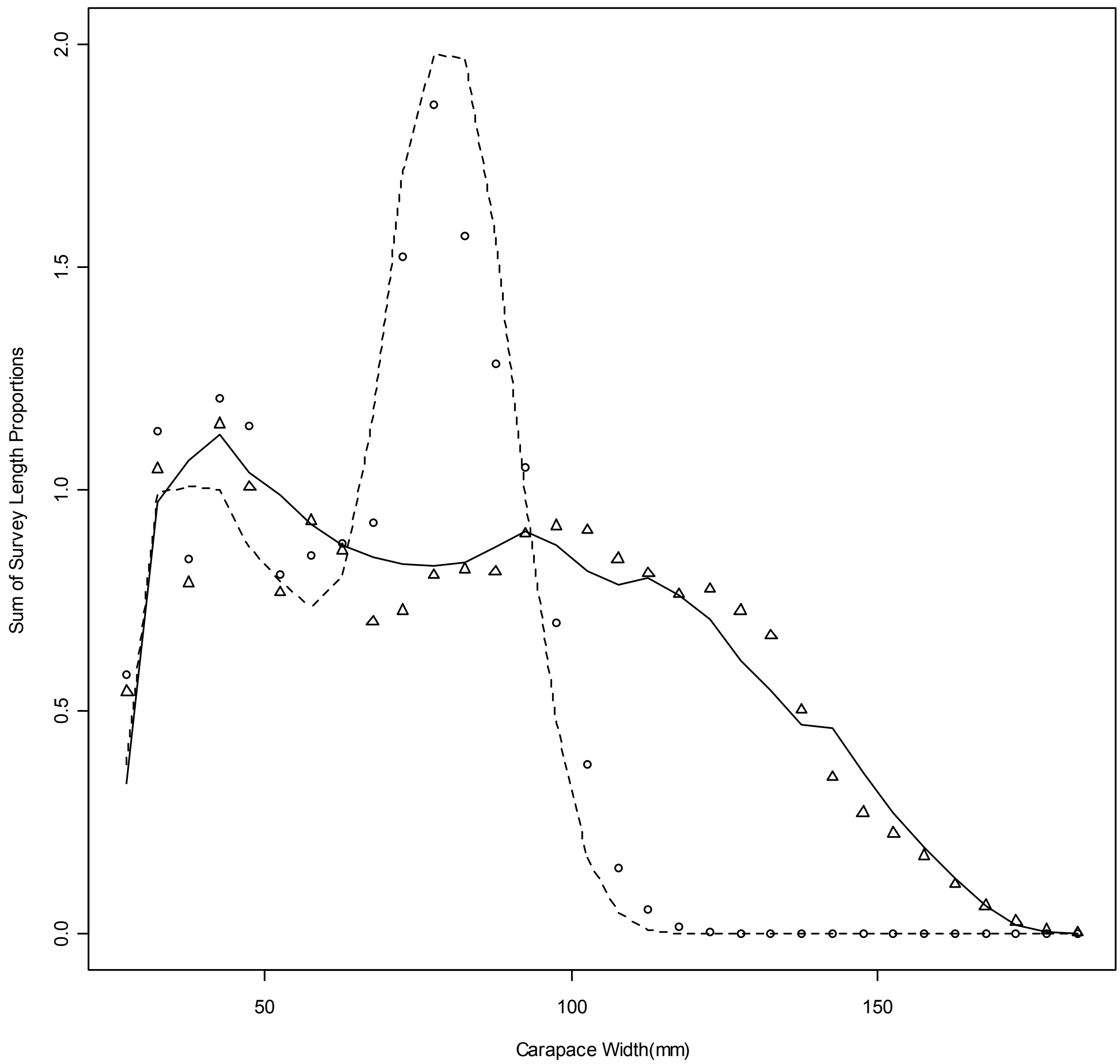


Figure A-23. Summary model fit to the survey male (solid line) and female (dotted line) size frequency data, all shell conditions combined. Symbols are observed data.

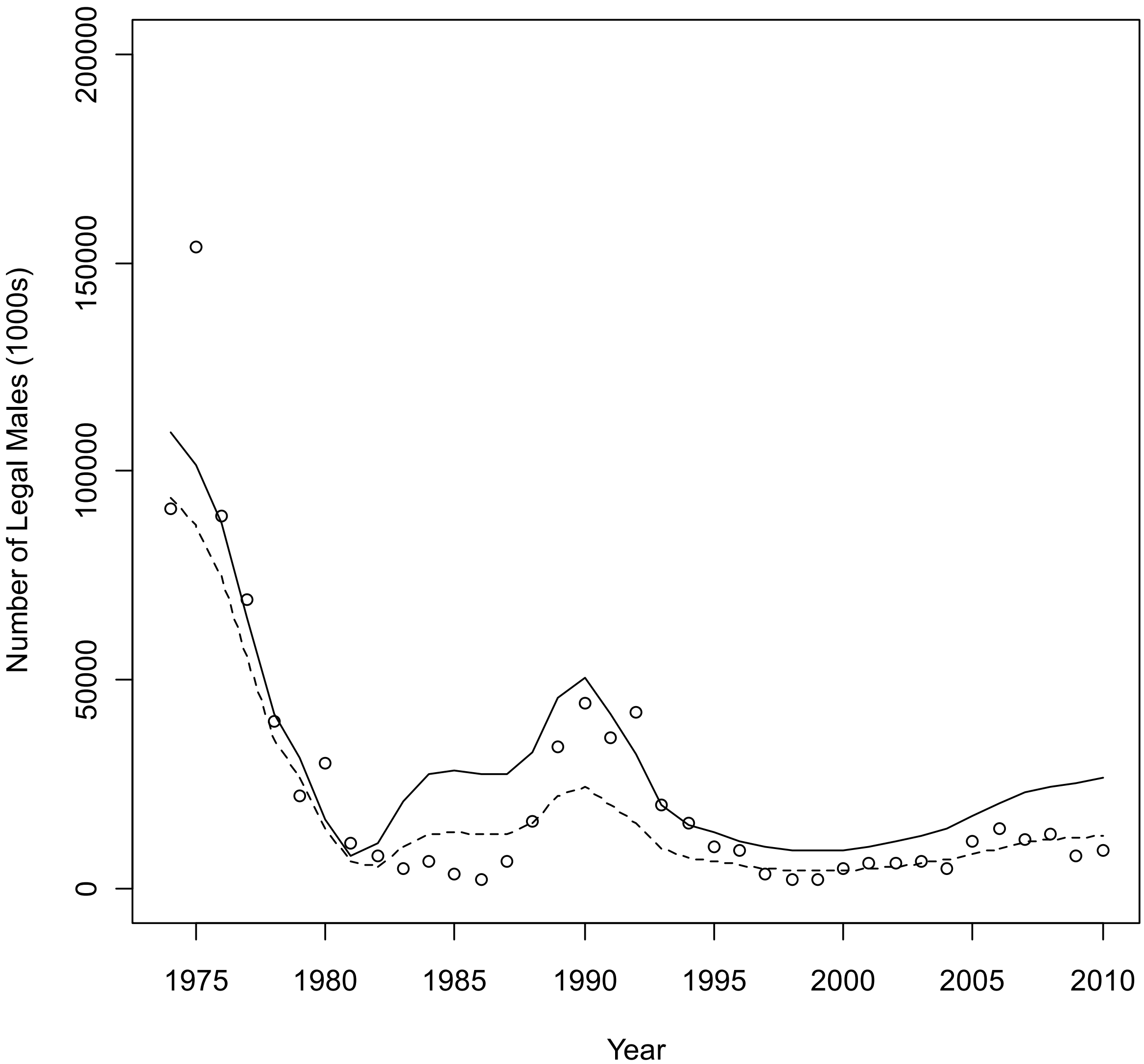


Figure A-24. Observed survey numbers of males ≥ 138mm (circles), model estimates of the population number of males ≥ 138mm (solid line) and model estimates of survey numbers of males ≥ 138mm (dotted line).

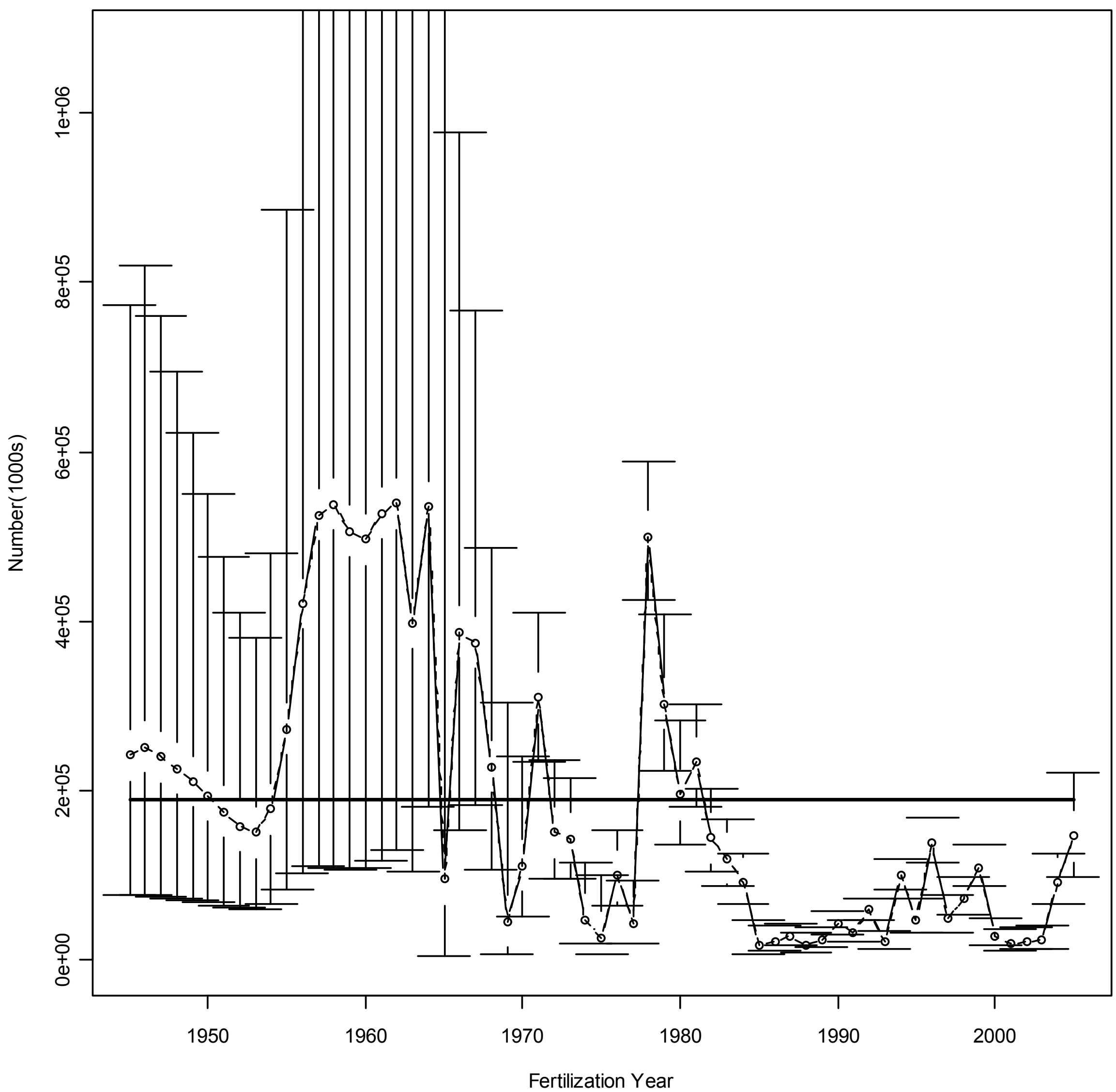


Figure A-25. Recruitment to the model for crab 25 mm to 50 mm by fertilization year. Total recruitment is 2 times recruitment in the plot given that male and female recruitment is set to be equal. Solid horizontal line is average recruitment.

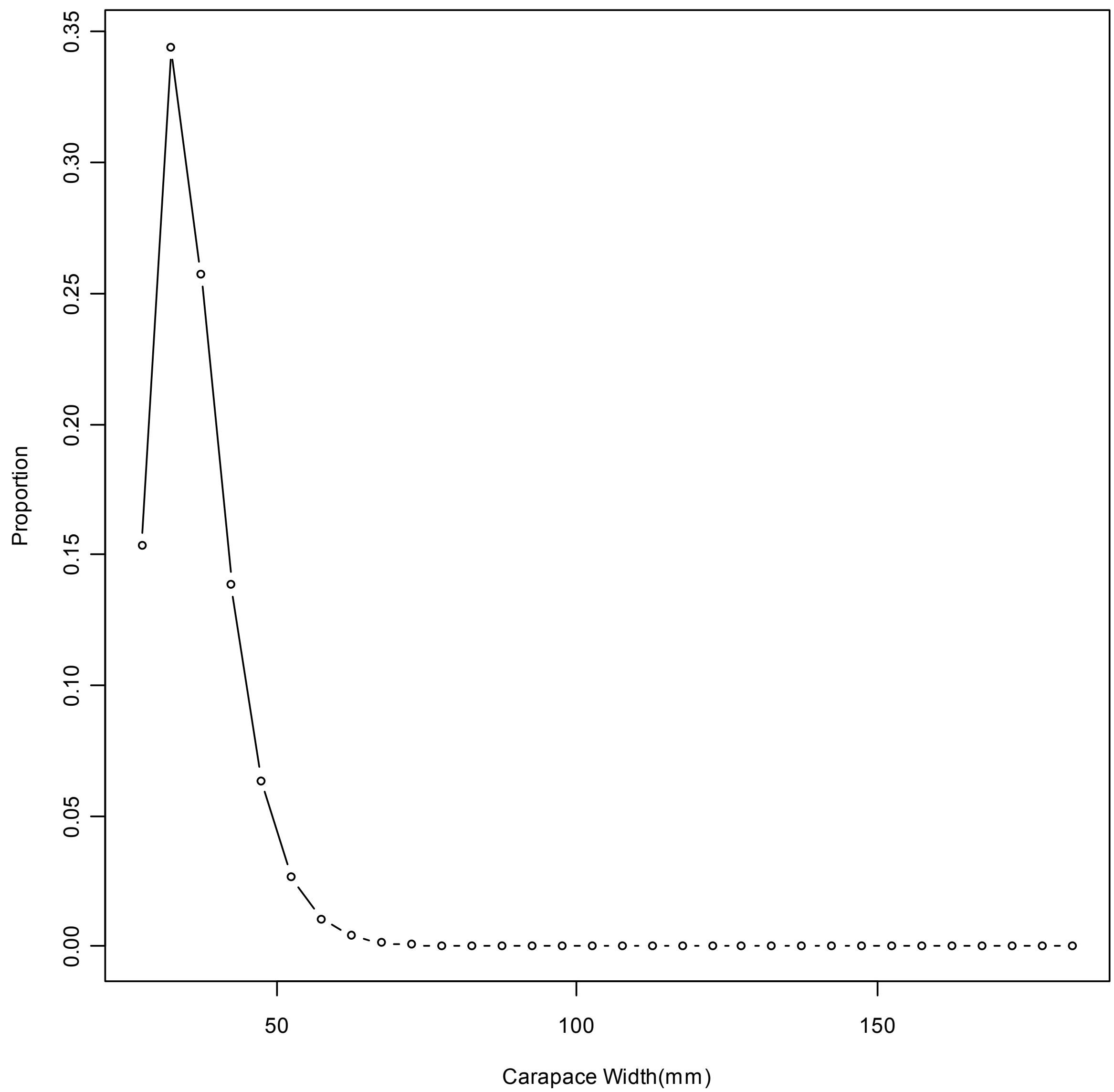


Figure A-26. Distribution of recruits to length bins estimated by the model.

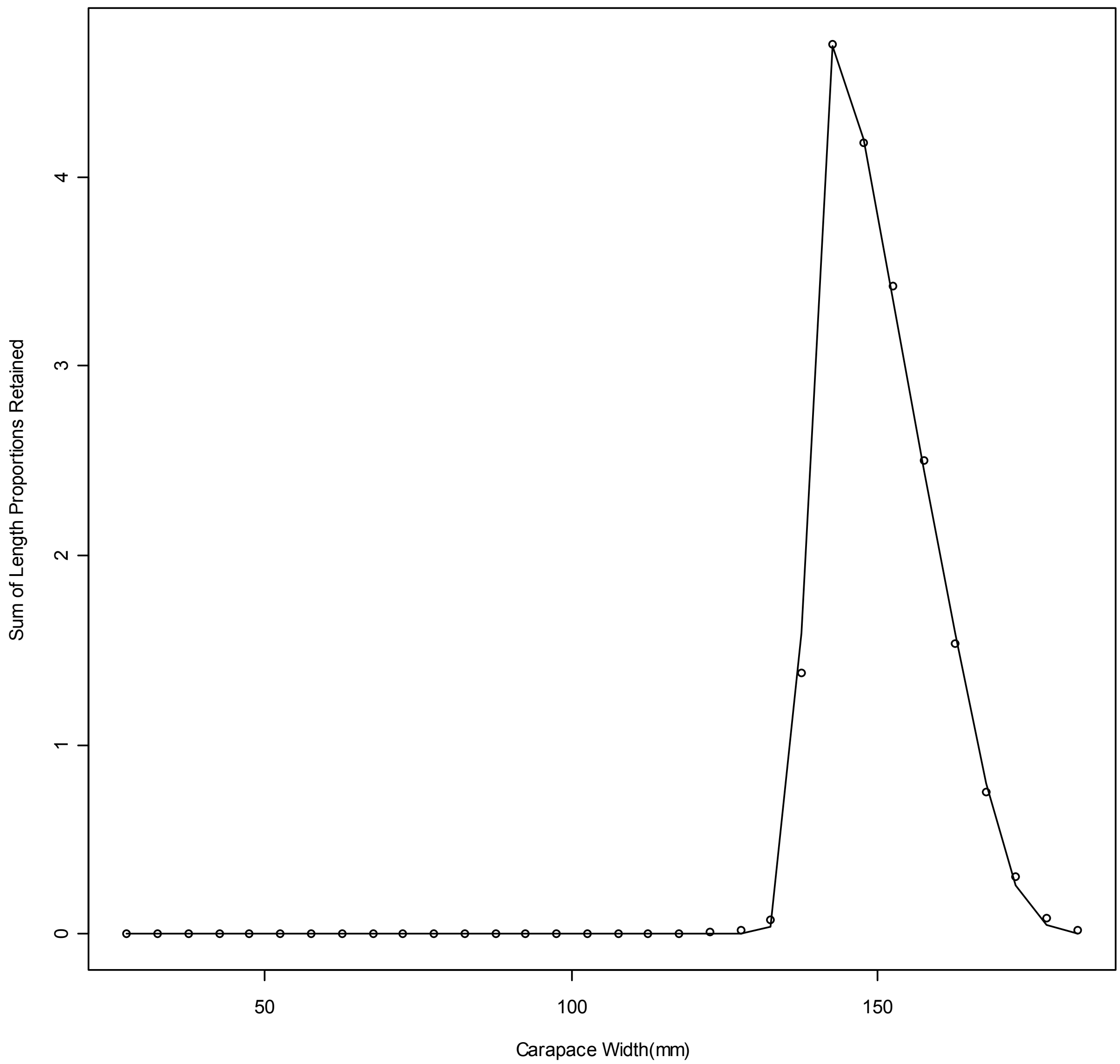


Figure A- 27. Summary model fit to the retained male size frequency data, shell condition combined. Solid line is the model fit. Circles are observed data.

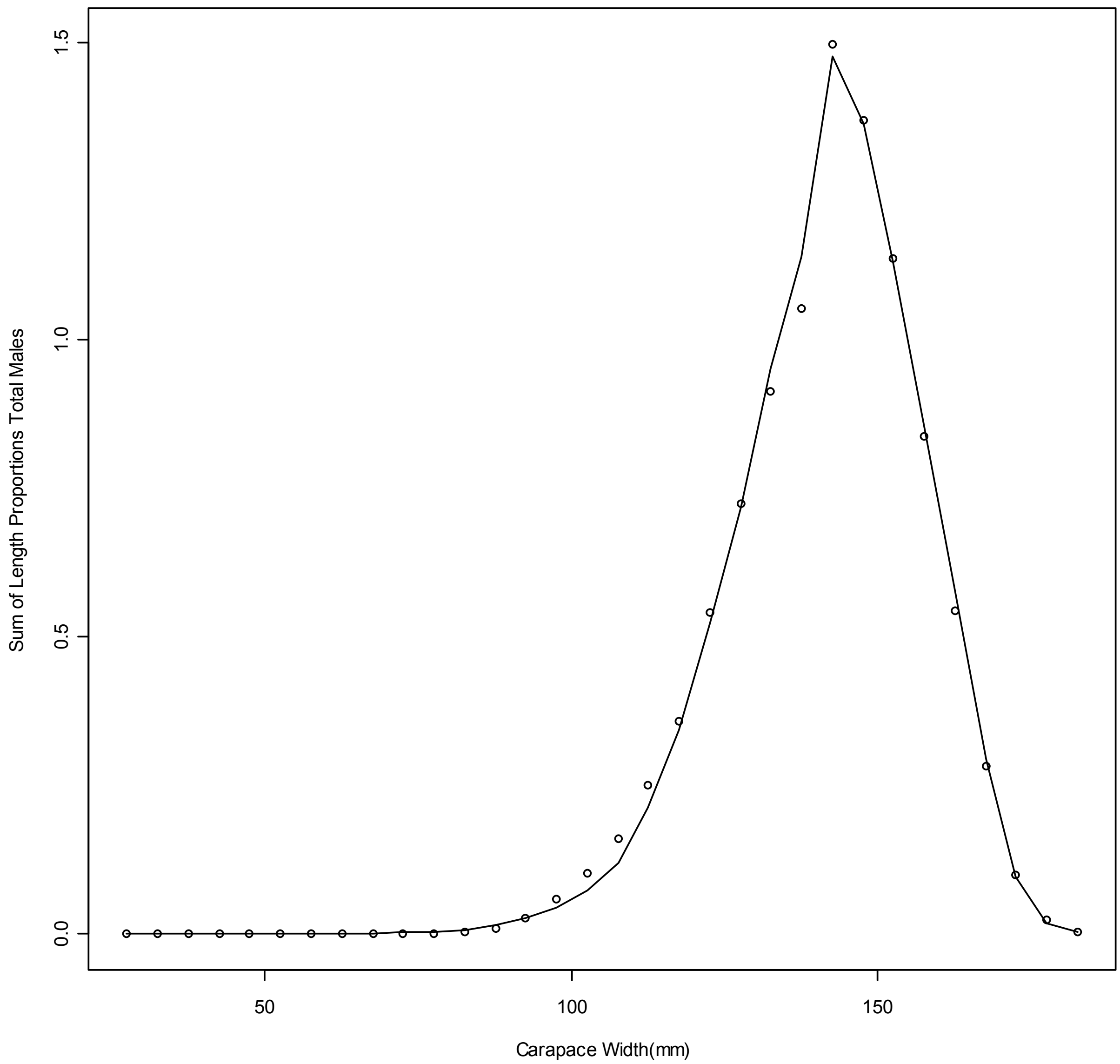


Figure A-28. Summary model fit to the total (discard plus retained) male size frequency data, shell condition combined. Solid line is the model fit. Circles are observed data.

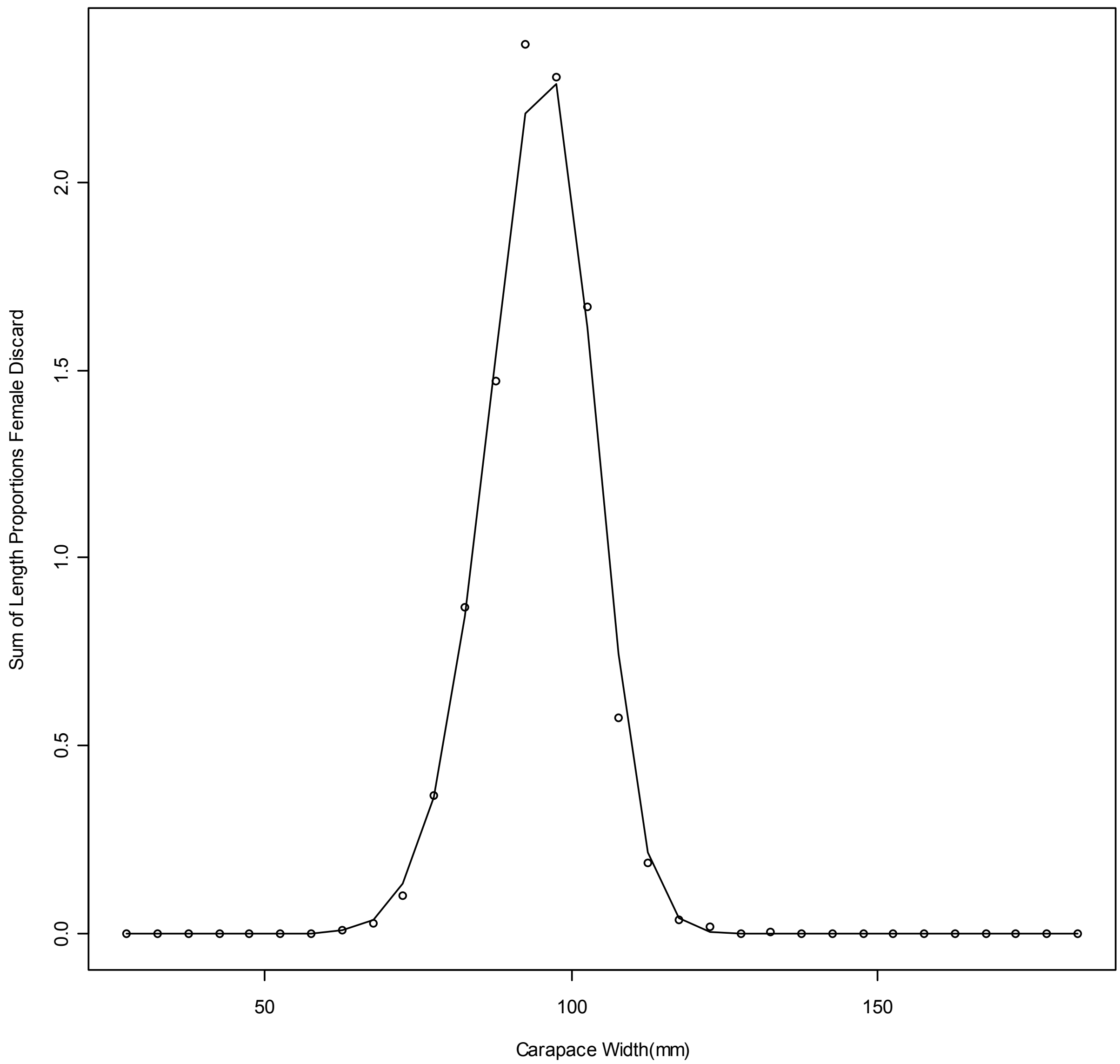


Figure A- 29. Summary model fit to the discard female size frequency data in the directed fishery. Solid line is the model fit. Circles are observed data.

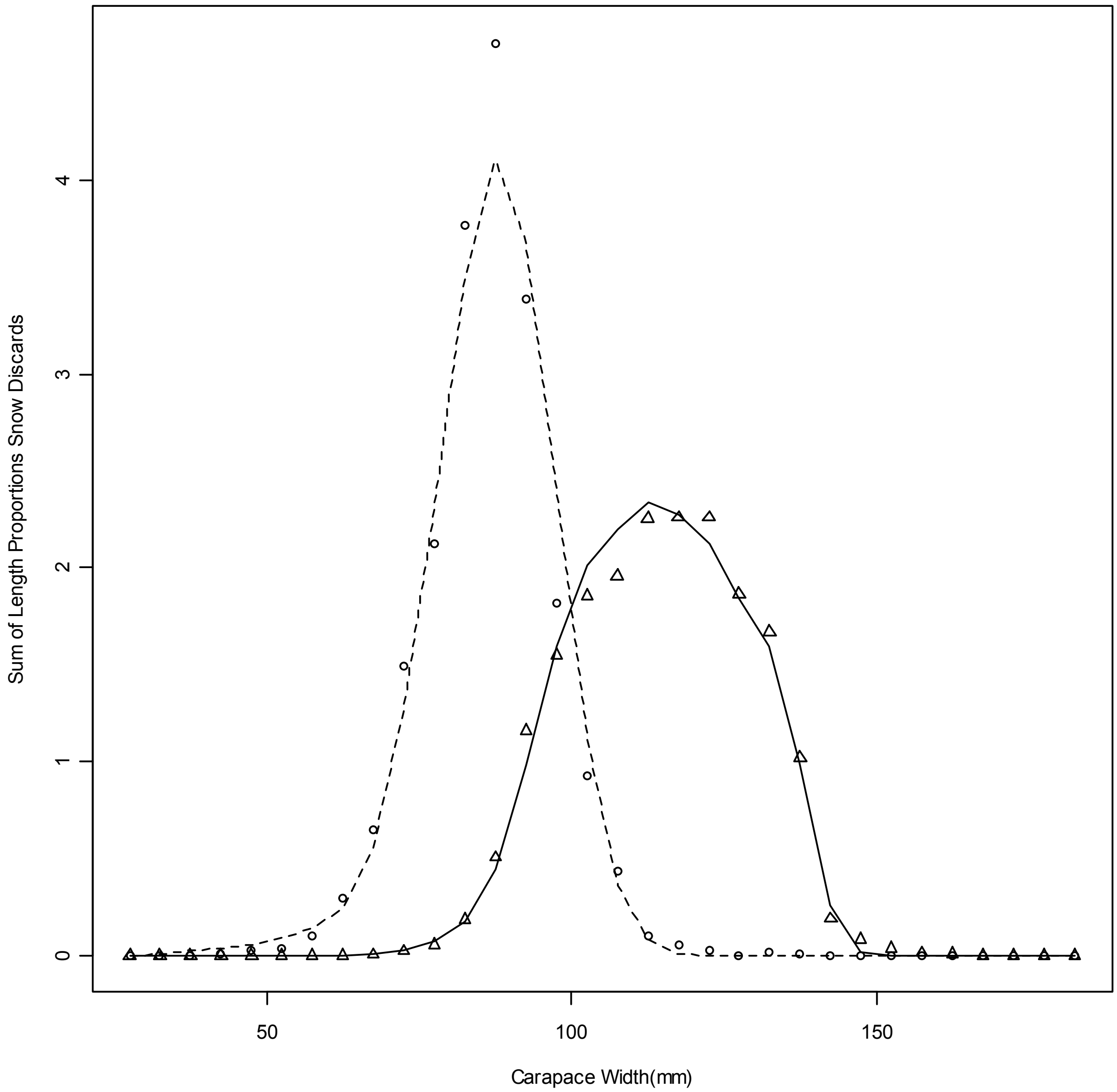


Figure A- 30. Summary model fit to the discards in the snow crab fishery for males (solid line) and females (dotted line) size frequency data. Symbols are observed data.

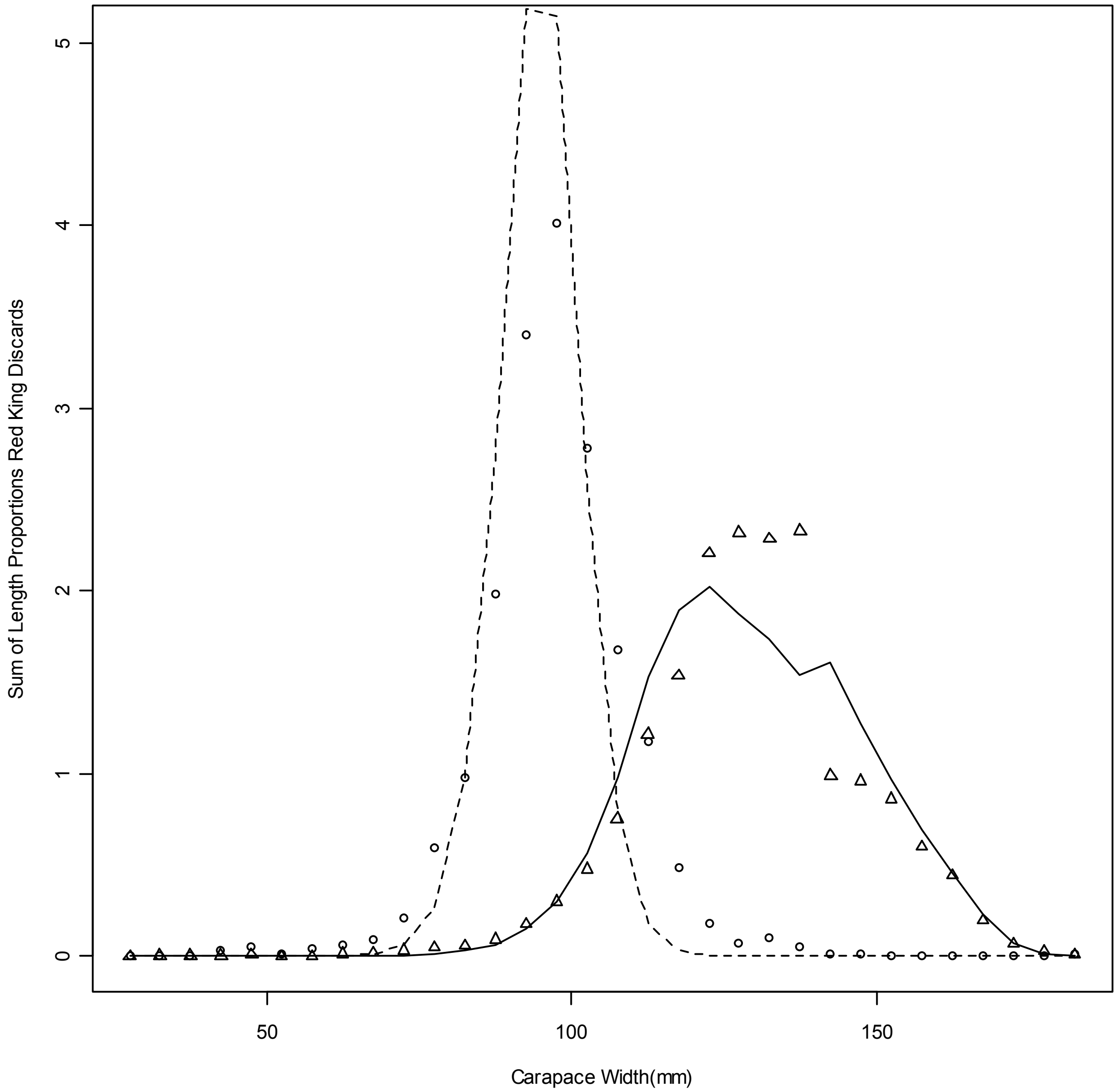


Figure A- 31. Summary model fit to the discards in the Bristol Bay red king crab fishery for males (solid line) and females (dotted line) size frequency data. Symbols are observed data. Currently, parameters fixed.

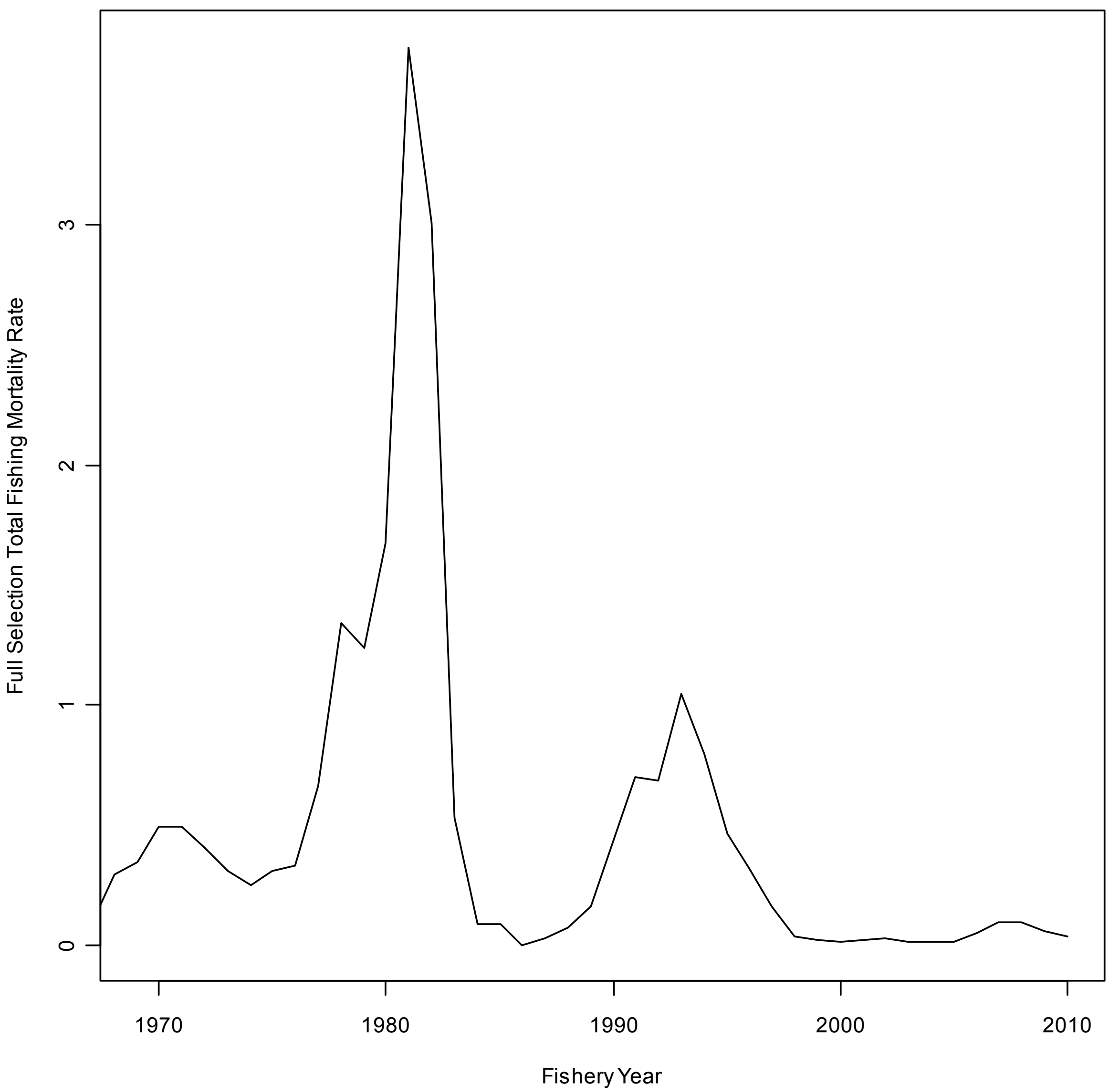


Figure A-32. Full selection total fishing mortality rates estimated in the model from 1970 to 2010 fishery seasons (1974 to 2009 survey years).

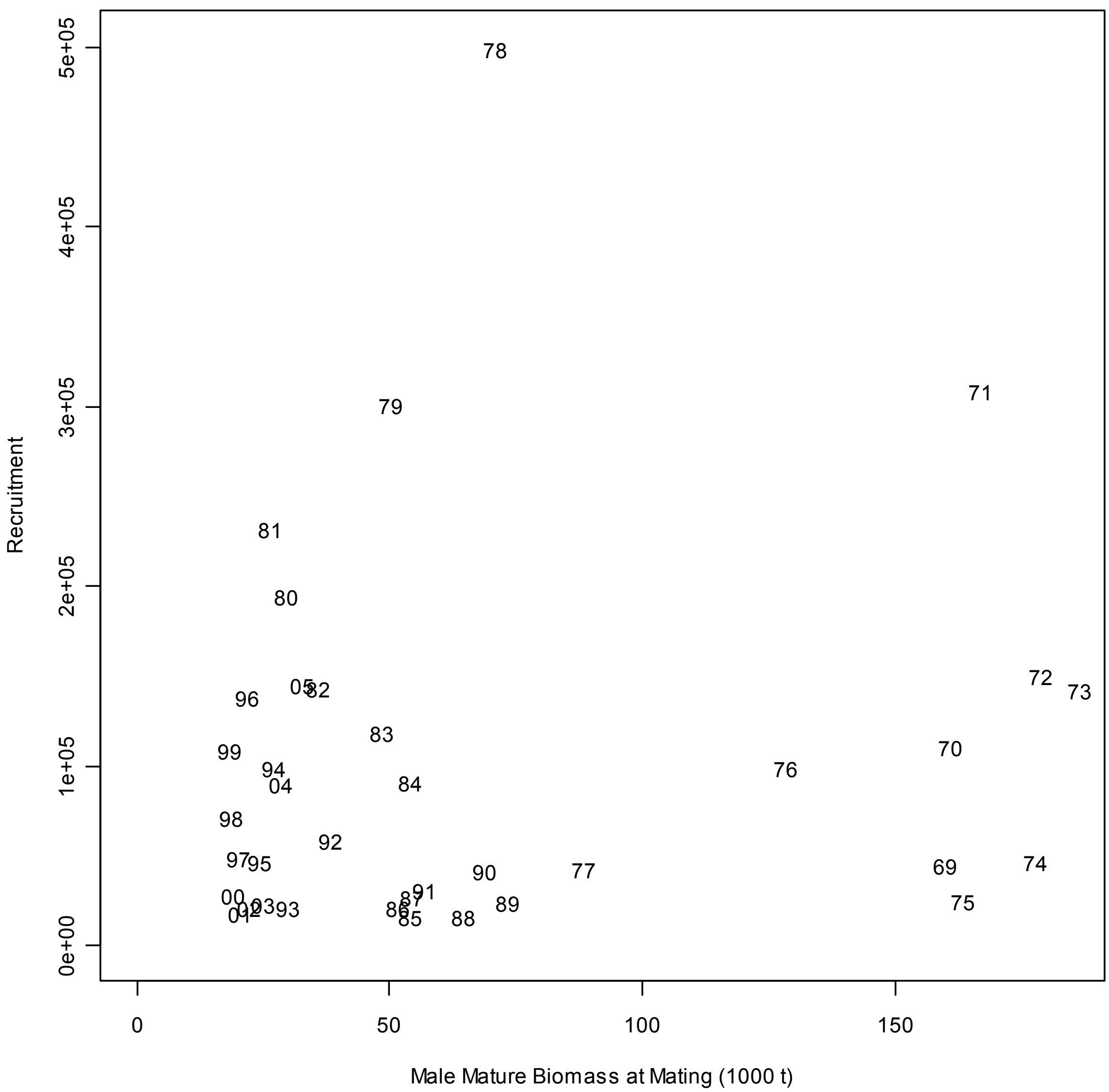


Figure A-33. Recruitment (1000 of crab) vs. male mature biomass at the time of mating (1000 t). Two digit year numbers are fertilization year assuming a lag of 5 years. Recruitment is one-half of total recruits.

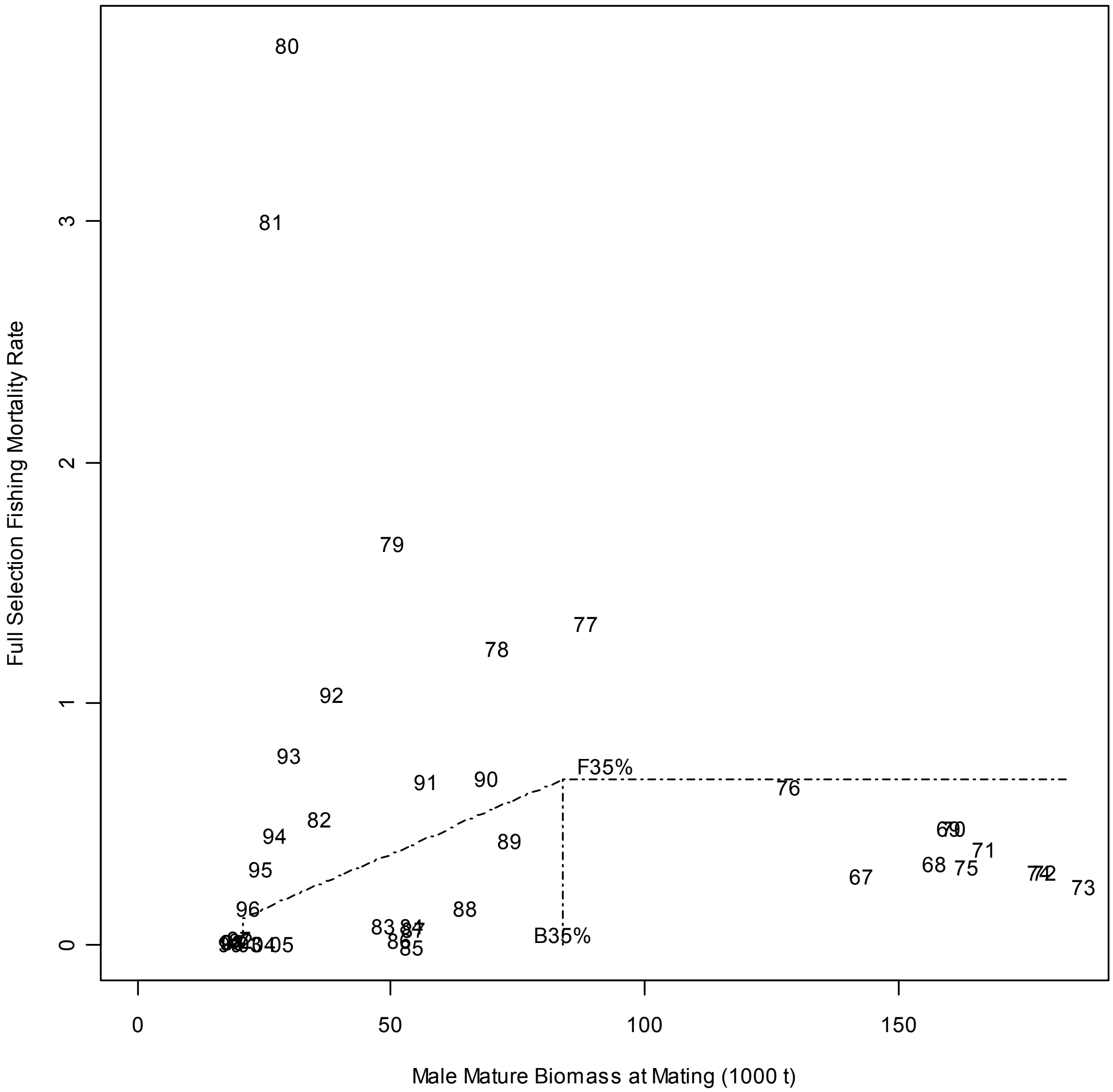


Figure A-34. Fishing mortality estimated from fishing years 1970 to 2009/10 (label 10 in the plot). The OFL control rule (F35%) is shown for comparison. The vertical line the location of the B_{MSY} proxy B35%.

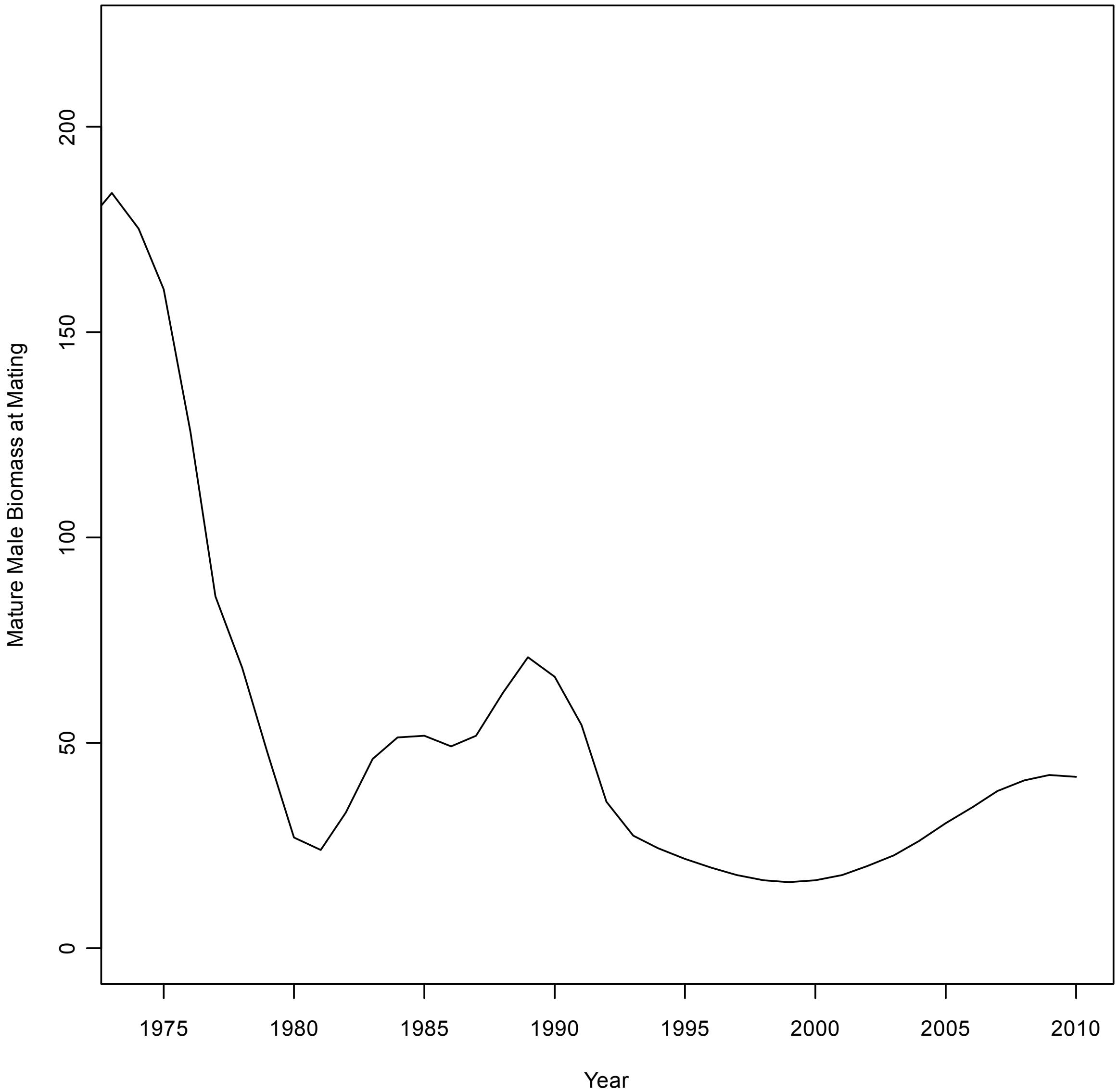


Figure A-35. Time-trajectory of mature male biomass at the time of mating for EBS Tanner crab (1000 t) for years 1974-2010.

Appendix B.

Table B-1. Tanner crab management plan stock data table.

Year	Survey Recruit Biomass (1000 t)	MMB/B_{MSY}	Mature Biomass @Mating MMB (1000 t)	MFB (1000 t)	μ_{LMB} = Retained / LMB@ Fishery	Average F LMB@ Fishery (Retained)	Catch Biomass Retained (1000 t)	Total (1000 t)	Survey MMB Abundance (10^6 Crab)	Biomass (1000 t)	Survey FMB Abundance (10^6 Crab)	Biomass (1000 t)
1965/66							1.92	11.99				
1966/67							2.44	18.45				
1967/68							13.60	59.12				
1968/69							18.00	68.72				
1969/70							27.49	104.16				
1970/71							25.49	100.11				
1971/72							20.71	87.97				
1972/73							16.90	66.09				
1973/74							13.03	60.02				
1974/75	*n/a*	1.72	143.20	*n/a*	0.18	0.20	15.24	74.45	349.84	206.29	276.35	94.87
1975/76		2.28	189.99		0.12	0.12	17.65	67.22	356.07	257.02	198.31	65.99
1976/77		1.02	85.12		0.36	0.44	30.02	99.06	221.89	151.60	222.97	81.13
1977/78		0.71	58.90		0.51	0.72	35.52	115.30	205.74	129.63	247.22	80.82
1978/79		0.42	34.86		0.56	0.83	21.09	72.90	135.50	79.18	142.24	45.89
1979/80		0.14	11.71		0.94	2.81	19.01	65.23	95.10	48.14	120.22	34.19
1980/81		0.71	59.32		0.49	0.67	13.43	50.12	260.96	95.65	420.27	111.32
1981/82		0.47	39.17		0.54	0.77	4.99	18.63	147.92	55.51	253.33	67.31
1982/83		0.43	36.06		0.40	0.51	2.39	9.09	107.93	46.84	369.80	96.63
1983/84		0.26	21.94		0.14	0.15	0.55	3.12	63.84	27.22	113.08	32.89
1984/85		0.20	16.89		0.25	0.29	1.43	6.60	49.19	23.18	77.64	23.92
1985/86		0.11	8.78		0	0	0	1.46	23.12	11.01	29.29	9.68
1986/87		0.13	10.86		0	0	0	2.04	40.46	13.74	25.54	7.85
1987/88		0.24	19.66		0.19	0.21	1.00	7.28	84.02	26.76	103.68	28.12

Table B-1. Tanner Crab management plan stock data table. (continued)

Year	Survey Recruit Biomass (1000 t)	MMB/B_{MSY}	Mature Biomass @Mating MMB (1000 t)	MFB (1000 t)	μ_{LMB} = Retained / LMB@ Fishery	Average F LMB@ Fishery (Retained)	Catch Biomass Retained (1000 t)	Total (1000 t)	Survey MMB Abundance (10^6 Crab)	Biomass (1000 t)	Survey FMB Abundance (10^6 Crab)	Biomass (1000 t)
1988/89		0.56	46.81		0.22	0.25	3.18	19.77	164.21	65.02	156.57	51.64
1989/90		0.81	67.16		0.38	0.49	11.11	51.75	237.22	105.65	163.65	48.96
1990/91		0.57	47.86		0.45	0.60	18.19	90.41	202.23	103.60	219.80	66.72
1991/92		0.68	56.41		0.46	0.62	14.42	80.53	218.32	108.34	254.94	79.42
1992/93		0.72	59.89		0.45	0.60	15.92	65.28	184.41	104.33	147.10	45.65
1993/94		0.42	35.16		0.46	0.61	7.67	33.62	104.46	58.76	62.91	19.41
1994/95		0.32	26.36		0.26	0.30	3.54	17.77	68.19	40.12	53.78	17.06
1995/96		0.24	20.34		0.23	0.26	1.92	11.19	51.80	29.62	72.51	22.37
1996/97		0.22	18.70		0.11	0.11	0.82	4.71	44.51	24.28	55.53	17.05
1997/98		0.09	7.42		0	0	0	3.36	24.41	10.43	21.06	6.26
1998/99		0.08	7.07		0	0	0	3.32	26.36	9.99	16.66	4.67
1999/00		0.12	10.29		0	0	0	1.52	40.36	12.80	29.30	8.29
2000/01		0.16	13.20		0	0	0	1.02	39.30	15.93	25.75	7.78
2001/02		0.17	14.51		0	0	0	1.66	54.49	17.79	37.44	9.74
2002/03		0.17	13.98		0	0	0	1.45	48.85	17.06	36.18	8.90
2003/04		0.23	19.56		0	0	0	0.72	68.02	23.19	55.82	14.13
2004/05		0.25	20.83		0	0	0	0.86	70.04	24.73	30.85	8.06
2005/06		0.42	34.99		0.05	0.05	0.43	3.04	109.17	42.40	86.31	22.06
2006/07		0.63	52.84		0.08	0.09	0.96	5.90	181.26	64.72	145.98	37.07
2007/08		0.72	59.80		0.10	0.11	0.96	7.28	195.38	73.56	88.99	25.23
2008/09		0.61	50.80		0.07	0.07	0.88	4.51	133.15	61.60	73.05	20.62
2009/10		0.34	28.44		0.10	0.10	0.60	3.47	77.35	34.99	48.35	14.17
2010/11									70.71	32.08	36.88	10.25